Comparative Nutritive Value of Several Sorghum Grain Varieties and Hybrids

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The nutritive values of ten varieties and four hybrids of sorghum grain and one variety of corn were compared in rat growth and digestion studies. Significant differences in nutritive value were observed between varieties. Nutritive value was negatively correlated with protein digestibility, indicating that digestible sorghum grain protein had an adverse effect on rat growth.

Sorghum grain (*Sorghum vulgare*) ranks third, following rice and wheat, in world production as a cereal grain (Kramer, 1959). Yet, relatively little has been done to characterize its nutritive value. Lysine, threonine, and sulfur-containing amino acids were found not to be present in adequate levels in sorghum grain protein for the growth of young rats (Nawar *et al.*, 1970; Pond *et al.*, 1958; Waggle *et al.*, 1966). Agricultural Research Service reports (1955, 1963) indicate an apparent protein digestibility of grain sorghum protein of 12 to 48 as compared to a value of 60 and 80 for corn and wheat protein, respectively. As an animal feed, sorghum grain protein and energy have a lower digestibility than corn in all livestock species (National Research Council, 1964). There is considerable variation in seed type among varieties and hybrids produced in the United States, which suggests that there may be variation in nutritive value. This report deals with studies designed to compare the nutritive value of selected varieties and hybrids of sorghum grain as indicated by chemical analysis for protein and amino acids and growth and digestion experiments with rats.

EXPERIMENTAL

Experiment 1. Twenty-eight varieties of sorghum grain were selected to characterize the protein content of sorghum grain seed stocks available. They were obtained from seed stocks produced under uniform conditions in a nursery at the Texas Agricultural Experiment Station at Lubbock, Texas. These were short, early-maturing types selected to represent a diversity in seed size, color, and hardness. They were analyzed for protein content by the Kjeldahl procedure (A.O.A.C., 1960).

Experiment 2. This experiment was conducted to obtain necessary preliminary information on the ability of sorghum grain alone and supplemented with protein or amino acids to promote growth of weanling rats and to study the effects of the supplements on the digestibility of sorghum grain protein and nonprotein organic matter. Four diets were formulated with the composition shown in Table I. The Martin (B 398) variety of sorghum grain was used in diets I, II, and III and was finely ground in a burr mill. All diets were supplemented with sufficient vitamins, minerals, and essential fatty acids to meet the rat's total requirement for these nutrients. Each diet was fed, *ad libitum*, for 12 days to six male, weanling, albino rats weighing 50 to 60 g. The rats were housed in individual wire-bottom cages in a controlled-temperature room (23 ± 2° C). Diet intake and body weights were recorded every 2 days. Feces were collected for digestibility determinations on a small wire screen suspended approximately 5 cm below the cages. The diets were analyzed for protein by the Kjeldahl procedure (A.O.A.C., 1960), the moisture content by vacuum drying at 60° C, the ash content by combustion at 600° C, and nonprotein organic matter was calculated by difference. Apparent digestibilities were determined by standard procedures (Maynard and Loosli, 1962) and true protein digestibility was calculated assuming metabolic fecal nitrogen excretion equal to 0.5 g of nitrogen per 100 g of dry matter intake. The data were analyzed statistically using Duncan's multiple range test (1955).

Experiment 3. The objective of this experiment was to compare the growth, feed intake, and feed efficiency of rats fed 10 varieties of sorghum grain and one variety of corn (Texas 60) and to compare the digestibilities of the sorghum grain and corn protein and nonprotein organic matter. The varieties were selected to represent some of the variation in seed type and to be representative of varieties used in commercial hybrid production. The sorghum grain and corn used were produced in 1965 in experimental plots under similar conditions of soil type, moisture, and fertility. The grains were incorporated into diets formulated as diet I of experiment 2. As formulated, the grains furnished all of the dietary protein and approximately 90% of the dietary energy. The diets were fed for 28 days and feces was collected over a 6-day period during the feeding trial. The amino acid content of single samples of the grains was determined with an amino acid analyzer (Technicon Chromatography Corporation, 1964). Hydrolysates were prepared by placing the samples in 200 volumes of 6 *N* HCl in a flask; the flask and contents were partially evacuated and then heated in an autoclave at 121° C for 24 hr. Other experimental procedures used were the same as those described for experiment 2.

Experiment 4. This experiment was conducted to compare the growth, feed intake, feed efficiencies, and digestion of protein and nonprotein organic matter by rats fed four selected varieties of sorghum grains and four hybrids produced from these varieties. The varieties used were SA 7078, Texas 414, Combine Kafir (B 3197), and Martin (B 398). The hybrids used were RS 610 (7078 × Kafir), RS 626 (414 × Kafir), RS 608 (7078 × Martin), and RS 625 (414 × Martin). The grains were produced in 1966 at the same location under

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Table I. Composition of Experimental Diets

Ingredients	Diet I, sorghum grain %	Diet II, sorghum grain plus amino acids %	Diet III, sorghum grain plus casein %	Diet IV, casein %
Sorghum grain[a]	88.55	79.45	77.30	
Corn starch				34.15
Sucrose				34.15
Casein[b]			11.25	20.25
Amino acid mixture[c]		7.60		
Corn oil[d]	5.00	5.00	5.00	5.00
Vitamin mixture[e]	2.20	2.20	2.20	2.20
Mineral mixture[f]	4.00	4.00	4.00	4.00
$NaHCO_3$		1.50		
Chlortetracycline[g]	0.25	0.25	0.25	0.25
Antioxidant[h]				

[a] See text for varieties used. [b] "Vitamin-free" casein, General Biochemicals, Inc., Chagrin Falls, Ohio. DL-Methionine was added to the casein to furnish 0.25 g per 100 g of the mixed diet. [c] Formulated to furnish the following quantities of amino acid per 100 g of mixed diet: DL-methionine, 0.3 g; L-lysine, 1.0 g; L-cystine, 0.2 g; L-tryptophan, 0.2 g; L-threonine, 0.5 g; L-valine, 0.5 g; L-isoleucine, 0.5 g; L-glutamic acid, 4.0 g; L-aspartic acid, 0.4 g. [d] Crisco, Procter & Gamble, Cincinnati, Ohio. [e] "Vitamin Fortification Mixture," Nutritional Biochemicals Corp., Cleveland, Ohio, to furnish the following amounts of vitamins per 100 g of diet: Vit. A, 1980 I.U.; Vit. D, 220 I.U.; α-tocopherol, 11 mg; ascorbic acid, 99 mg; inositol, 11 mg; choline chloride, 165 mg; menadione, 5 mg; *p*-amino benzoic acid, 11 mg; niacin, 9.9 mg; riboflavin, 2.2 mg; pyridoxine·HCl, 2.2 mg; thiamine·HCl, 2.2 mg; calcium pantothenate, 6.6 mg; biotin, 44 μg; folic acid, 198 μg; Vit. B_{12}, 3 μg. [f] "Jones and Foster" mixture, General Biochemicals, Inc., Chagrin Falls, Ohio, furnishing the following salts per 100 g of diet: NaCl, 0.557 g; KH_2PO_4, 1.556 g; $CaCO_3$, 1.526 g; $MgSO_4$, 0.229 g; $FeSO_4 \cdot 7H_2O$, 0.108 g; $CuSO_4 \cdot 5H_2O$, 20 μg; $MnSO_4 \cdot 2H_2O$, 180 μg; KI, 320 μg; $CoCl_2 \cdot 6H_2O$, 0.8 μg; $ZnCl_2$, 12 μg. [g] Aureofac-10 containing 2.2% chlorotetracycline, American Cyanamid Co., Princeton, New Jersey. [h] Santoquin, Monsanto Chemical Co., St. Louis, Mo., added to the diets to furnish a level of 0.0125%.

the same conditions described for the grains used in experiment 3. Experimental procedures were the same as those described for experiment 3 except that the diets were fed for 24 days rather than 28 days.

RESULTS AND DISCUSSION

Experiment 1. Results of protein analyses of 27 varieties of sorghum grain are shown in Table II. A variation was found in protein content among varieties of 7.9 to 15.2%. A tendency for related varieties to fall in the same range of protein content was noted, *i.e.*, the Hegaris were low, Kafirs were in the medium range, while some of the Feteritas contained the highest level of protein. Associated genetic studies with certain of these varieties indicated that the protein content of the varieties was reflected in the protein content of hybrids produced from them (Breuer *et al.*, 1967). This work indicated that the mode of inheritance was a simple one in that the hybrids had a protein content of approximately the mean of the parents. Thus, it appeared that varieties of sorghum grain could be selected for high protein content and high protein hybrids could be produced from them.

Experiment 2. Results of the experiment to test different formulations of diets containing sorghum grain are shown in Table III. Sorghum grain without protein or amino acid supplement supported growth of only 12 to 13% of that of rats receiving casein-containing diets. However, the rats maintained a satisfactory appearance with a slight increase in feed intake throughout the experiment. Supplements of either casein or amino acids had no effect on the digestibility

Table II. Protein Analyses of Varieties of Sorghum Grain (Exp. 1)

Variety	Protein[a] %
Hegari (Early)	7.9
Hegari (Combine)	8.1
Texas 2536	10.4
Texas 2521	10.9
Darset 28	11.1
Texioca 54	11.1
Durra (Dwarf, white)	11.2
Texas Milo	11.5
Kafir (Pink)	11.9
Sumac	11.9
Atlas	12.1
Shallu (Combine)	12.2
Shantung Brown Kaoliang	12.3
SA 7078	12.6
Caprock (SA 7000)	12.7
Kafir 60	12.7
Kafir (Golden)	12.8
California 38	13.1
Feterita (09)	13.2
Redlan (B 378)	13.5
Feterita (Spur)	13.5
Texas 2537	13.8
Pop Sorghum	14.0
Martin (B 398)	14.0
Redbine 60	14.9
Feterita (Double-dwarf)	15.1
Feterita (Double-dwarf, waxy)	15.2

[a] Values expressed on a 90% dry matter basis.

of sorghum grain nonprotein organic matter and little or no effect on sorghum grain protein digestibility when allowances were made for the digestibility of the amino acids and casein added to the diets. Thus, it appeared that the desired comparison among sorghum grains for nutritive value and digestibility could be made by feeding rats diets containing only sorghum grain and supplemental vitamins, minerals, and essential fatty acids.

Experiment 3. Protein and amino acid analyses of the grains fed in experiment 3 are shown in Table IV. The sorghum grains had a higher protein content than the corn. The sorghum grains did not show as wide a range in protein content as that observed in experiment 1. However, the varieties ranked in protein content in approximately the same order as previously observed. The increase in protein content in the high-protein varieties was due in large measure to increases in levels of leucine and nonessential amino acids which are constituents of the prolamine fraction of cereal proteins. This observation agrees with previous reports (Vavich *et al.*, 1959; Waggle *et al.*, 1966). Results of the feeding and digestibility comparisons are shown in Table V. The best performance was observed in rats fed the corn diet. A range in daily gain of 0.47 to 1.27 g was present in rats fed the different sorghum grain varieties. Gains of rats fed the SA 7078, Hegari, Caprock, and Martin varieties were significantly greater ($P < 0.05$) than those of rats fed the Tx 414, Kafir, Feterita, and Shallu varieties. Rats fed all diets consumed similar quantities of protein so that the values for protein efficiency ratio showed the same pattern as the gains. Protein digestibility was lower for varieties supporting the best growth. Protein digestibility was significantly negatively correlated with gain ($P < 0.01$), feed intake ($P < 0.05$) and protein efficiency ratio ($P < 0.01$). Significant differences, although quantitatively small, were found in the digestibility of nonprotein organic matter between several varieties.

Table III. Comparisons of Different Formulations of Diets Containing Sorghum Grain (Exp. 2)[a]

Diet	Weight gain, g	Feed intake, g	Feed efficiency, g of gain/ g of feed	True protein digestibility, %	Nonprotein organic matter digestibility, %
I. Sorghum grain	0.58[a]	8.3[a]	0.07[a]	86.1[a]	91.6[a]
II. Sorghum grain plus amino acids	3.00[b]	10.0[b]	0.30[b]	89.4[b]	91.9[a]
III. Sorghum grain plus casein	4.75[c]	12.2[c]	0.40[c]	92.1[b]	91.5[a]
IV. Casein	4.41[b,c]	10.4[b]	0.42[c]	100.0[c]	99.0[b]

[a] Treatment means given as daily averages of six rats fed each diet for 12 days. Means without a common letter in their superscript are significantly different ($P < 0.05$).

Table IV. Protein and Amino Acid Composition of Test Grains (Exp. 3)[a]

Variety	Corn	Hegari	Wheatlan	Kafir	Caprock	Shallu	7078	Redlan	Tx 414	Martin	Feterita
% Protein ($N \times 6.25$)	9.3	10.7	10.9	11.1	11.6	11.6	11.6	12.0	12.1	13.0	13.4
Amino acids, %											
Lysine	0.26	0.22	0.22	0.23	0.23	0.22	0.24	0.21	0.26	0.25	0.25
Methionine	0.18	0.18	0.17	0.19	0.17	0.19	0.16	0.18	0.16	0.20	0.19
Threonine	0.38	0.32	0.38	0.38	0.38	0.30	0.39	0.43	0.41	0.43	0.47
Isoleucine	0.31	0.44	0.39	0.40	0.48	0.43	0.44	0.48	0.62	0.48	0.51
Leucine	1.10	1.48	1.40	1.40	1.39	2.47	1.49	1.84	1.64	1.73	1.86
Histidine	0.30	0.26	0.26	0.27	0.28	0.28	0.30	0.29	0.30	0.32	0.32
Phenylalanine	0.43	0.54	0.50	0.52	0.59	0.57	0.54	0.57	0.60	0.59	0.68
Tyrosine	0.37	0.38	0.44	0.44	0.47	0.48	0.45	0.50	0.50	0.50	0.57
Valine–Cystine[b]	0.51	0.61	0.47	0.60	0.61	0.47	0.62	0.61	0.60	0.70	0.64
Arginine	0.40	0.37	0.36	0.36	0.36	0.39	0.49	0.34	0.42	0.40	0.40
Alanine	0.73	0.95	1.00	1.03	1.11	1.00	1.03	1.09	1.05	1.21	1.22
Aspartic acid	0.70	0.75	0.78	0.86	0.87	0.65	0.78	0.90	0.80	1.00	0.93
Glutamic acid	1.85	2.49	2.49	2.50	2.65	2.29	2.76	2.65	2.74	2.91	3.16
Glycine	0.36	0.32	0.34	0.36	0.41	0.36	0.38	0.38	0.39	0.38	0.40
Proline	0.65	0.61	0.83	0.68	0.79	0.80	0.81	0.72	0.80	0.91	0.86
Serine	0.40	0.43	0.54	0.46	0.47	0.35	0.44	0.43	0.48	0.48	0.54
Ammonia	0.18	0.27	0.23	0.24	0.24	0.26	0.26	0.29	0.25	0.28	0.30

[a] 90% dry matter basis. [b] Not separated by analytical method. Independent analyses showed valine and cystine present in ratios of approximately 5:1.

Table V. Composition of Diets Containing Corn and Ten Varieties of Sorghum Grain (Exp. 3)[a]

Grain	Weight gain, g	Feed intake, g	Feed efficiency, g of gain/ g of feed	Protein intake, g	Protein efficiency ratio, g of gain/ g of protein	True protein digestibility, %	Nonprotein organic matter digestibility, %
Tx 414	0.47[a]	11.7	0.04[a]	1.25	0.38	80.6[b,c,d]	92.2[a,b]
Feterita	0.64[a]	11.5	0.06[a]	1.37	0.47	82.6[c,d]	90.5[f,g,h]
Kafir	0.69[a]	12.8	0.05[a]	1.26	0.55	81.2[b,c,d]	90.4[g,h]
Shallu	0.71[a]	12.1	0.06[a,b]	1.24	0.57	79.2[a,b,c,d]	91.9[a,b,c]
Wheatlan	0.84[a,b]	13.2	0.06[a,b]	1.27	0.66	77.4[a,b,c]	89.2[i]
Redlan	0.87[a,b]	12.8	0.07[a,b]	1.36	0.64	77.6[a,b,c]	92.2[a,b]
Caprock	1.09[b,c]	13.1	0.08[b]	1.35	0.81	77.8[a,b,c]	91.4[c,d,e]
SA 7078	1.13[b,c]	12.9	0.09[b,c]	1.32	0.86	76.3[a,b]	91.5[c,d]
Hegari	1.20[b,c,d]	13.7	0.09[b,c]	1.30	0.92	77.8[a,b,c]	90.1[h]
Martin	1.27[c,d]	12.6	0.10[c]	1.45	0.88	74.4[a]	90.8[f,g]
Corn	1.49[d]	12.6	0.12[c]	1.04	1.43	84.2[d]	91.0[d,e,f]

[a] Treatment means given as daily average for six rats fed diets for 28 days. Means without a common letter in their superscript are significantly different ($P < 0.05$).

Experiment 4. Results of protein and amino acid analyses of grains fed in this experiment are shown in Table VI. The varieties studied were somewhat lower in protein content than observed in experiments 1 and 3 but had a similar ranking in protein content. With the exception of the RS 610 variety, the hybrids had a protein content near the mean of the parents. There were only minor differences in amino acid content. Results of the feeding and digestion trial are given in Table VII. Although differences in daily gain were not as large as observed in experiment 3, they ranked similarly in promoting growth of rats. The hybrids closely resembled the seed parents in the promotion of rat growth. Again the rats ate to a near constant level of protein intake which was reflected in the protein efficiency ratio values. Also similar to experiment 3, there was a significant negative correlation between protein digestibility and gain ($P < 0.05$), feed intake ($P < 0.05$)

Table VI. Protein and Amino Acid Composition of Sorghum Grain (Exp. 4)[a]

Variety or hybrid	7078	Tx 414	Kafir	Martin	610 (7078 × Kafir)	626 (414 × Kafir)	608 (7078 × Martin)	625 (414 × Martin)
% Protein ($N \times 6.25$)	10.5	10.9	11.1	11.6	10.0	10.8	11.2	11.3
Amino acids, %								
Lysine	0.29	0.26	0.27	0.30	0.30	0.31	0.26	0.25
Methionine	0.15	0.18	0.18	0.20	0.15	0.17	0.16	0.19
Threonine	0.39	0.38	0.37	0.30	0.33	0.36	0.41	0.40
Isoleucine	0.34	0.43	0.39	0.45	0.35	0.42	0.44	0.48
Leucine	1.06	1.32	1.32	1.38	1.20	1.31	1.38	1.45
Histidine	0.29	0.27	0.28	0.30	0.28	0.33	0.28	0.30
Phenylalanine	0.44	0.50	0.45	0.51	0.40	0.47	0.51	0.53
Tyrosine	0.34	0.43	0.37	0.44	0.33	0.41	0.42	0.45
Valine–cystine	0.54	0.54	0.53	0.59	0.48	0.53	0.59	0.60
Arginine	0.39	0.40	0.39	0.42	0.38	0.38	0.38	0.42
Alanine	0.99	1.02	1.06	1.13	0.93	1.05	1.13	1.12
Aspartic acid	0.91	0.94	0.90	0.94	0.87	0.90	0.84	0.79
Glutamic acid	2.38	2.47	2.58	2.67	2.11	2.43	2.61	2.46
Glycine	0.37	0.37	0.35	0.39	0.34	0.36	0.37	0.38
Proline	1.03	0.70	0.98	0.73	0.95	0.68	0.64	0.74
Serine	0.37	0.44	0.44	0.49	0.39	0.46	0.46	0.47
Ammonia	0.24	0.26	0.22	0.30	0.20	0.27	0.28	0.33

[a] 90% dry matter basis.

Table VII. Comparisons of Diets Containing Four Sorghum Grain Varieties and Four Related Hybrids (Exp. 4)[a]

Grain	Weight gain, g	Feed intake, g	Feed efficiency, g of gain/ g of feed	Protein intake, g	Protein efficiency ratio, g of gain/ g of protein	True protein digestibility, %	Nonprotein organic matter digestibility, %
Tx 414	0.68	11.2	0.06[a]	1.08	0.63	85.9	93.9[c]
626 (414 × Kafir)	0.74	11.4	0.06[a]	1.09	0.68	83.7	94.2[c,d]
610 (7078 × Kafir)	0.75	11.8	0.06[a]	1.05	0.71	81.6	94.6[e]
Kafir	0.82	11.6	0.07[a,b]	1.14	0.72	78.7	92.7[a]
608 (7078 × Martin)	0.89	12.0	0.07[a,b]	1.19	0.75	82.3	93.3[b]
Martin	0.92	12.0	0.08[b]	1.23	0.75	81.4	94.4[e]
625 (414 × Martin)	0.94	12.0	0.08[b]	1.20	0.78	79.7	94.6[e]
SA 7078	0.96	12.0	0.08[b]	1.12	0.86	80.9	94.0[c,d]

[a] Treatment means given as daily average for six rats fed diets for 24 days. Means without a common letter in their superscript are significantly different.

and protein efficiency ratio ($P < 0.05$). Small but significant differences were observed between varieties in nonprotein organic matter digestibility.

General. These data indicate that there are differences between varieties of sorghum grain in nutritive value. These differences appeared to be related to the utilization of the sorghum grain protein rather than the nonprotein organic matter. As reported by Waggle *et al.* (1966), differences in animal response were not correlated with either the protein or lysine content of the grains. Rather, the highest growth rates were associated with grains having the lowest protein digestibility. This may indicate that amino acids released from the prolamine and/or glutelin fractions of the sorghum grain protein were "imbalancing" the mixture of amino acids absorbed from the digestive tract. As suggested by Nesheim and Carpenter (1967), analysis for fecal nitrogen may not give an accurate estimate of the true availability of dietary amino acids since proteins may be digested in the large intestine resulting in the absorption of nitrogenous compounds other than the amino acids. Thus, sufficiently large differences may exist in the true availability of the sorghum grain amino acids to account for the observed rat responses.

These observations indicate that there may be no advantage so far as the nutrition of nonruminants are concerned in producing sorghum grain with high levels of digestible protein until improvements are made in the balance of amino acids present in sorghum grain or methods are developed for the specific supplementation of the sorghum grain protein.

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