Effects of Lime Cooking on Energy and Protein Digestibilities of Maize and Sorghum[1]

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ABSTRACT

Ileum-cannulated pigs were used in a 5 × 5 Latin square experiment to determine relative nutrient digestibilities of maize (*Zea mays* L.) and whole sorghum (*Sorghum bicolor* (L.) Moench) cooked with and without lime, and pearled sorghum cooked with lime. Addition of lime during the cooking of maize and whole sorghum for tortillas did not affect energy utilization of either grain but lowered nitrogen utilization significantly ($P < 0.05$). Nitrogen digestibility of lime-cooked whole sorghum was 90.5% that of lime-cooked maize at the ileum and 93.3% of lime-cooked maize over the total digestive tract. Dry matter, gross energy, and nitrogen digestibilities of lime-cooked pearled sorghum were significantly greater ($P < 0.05$) than those of lime-cooked whole sorghum and equal to or greater ($P < 0.05$) than those of lime-cooked maize. Average dry matter and gross energy digestibilities at both the end of the small intestine and over the entire digestive tract were lower ($P < 0.01$) for whole sorghum than for maize. Lime cooking significantly decreased apparent biological values for maize and whole sorghum ($P < 0.05$).

Sorghum and maize are important dietary staples for millions of people in the world. In several Latin American countries, maize is consumed in the form of tortillas, prepared by cooking the grain with lime ($Ca[OH]_2$). In Central America, sorghum is often used as an alternative to maize for tortilla production. Recent reports (Bedolla and Rooney 1982, Choto et al 1985) show that sorghum tortillas can be comparable to maize tortillas in color, texture, and overall acceptance. The potential acceptance of sorghum tortillas results from new food-grade white genotypes and improved processing technologies such as decortication. More information is required to compare the nutritional value of alkaline-cooked maize and sorghum products. MacLean et al (1982) reported that sorghum gruels fed to children were poorly digested. However, subsequent comparisons of extruded decorticated sorghums fed to children showed markedly improved nitrogen absorption and digestibility (MacLean et al 1983).

Alkali cooking has a beneficial effect on the bioavailability of niacin present in maize (Bressani et al 1958, Belvady 1975, Koetz and Neukom 1977); yet, it has a detrimental effect on protein quality and availability. Alkali cooking helps to form new peptides such as lysinoalanine, lanthionine, and ornithoalanine, which have lower protein quality and biological availability (De Groot and Slump 1969, Chu et al 1976).

Research (Sauer et al 1977a,b; Cousins et al 1981) has demonstrated differences in protein and amino acid digestibilities among cereals through the use of pigs fitted with cannulas near the end of the small intestine. Swine have digestive and physiological systems similar to humans and appear to be good models for human nutrition research (Dodds 1982). In addition, digestibilities determined from digesta collected near the end of the small intestine provide more accurate information, because the synthesis and degradation of amino acids by the microflora of the large intestine are eliminated (Zebrowska 1978, Just et al 1981). Cousins et al (1981) and Purser et al (1979) showed that the digestibility of sorghum protein for swine is about 5% less than the digestibility of maize protein, and the overall nutritional value of yellow sorghum is about 95% that of maize. All of the above experiments were conducted on raw ground grain. The objectives of the present study were: 1) to determine the effect of lime cooking on the nutritional value of whole sorghum and maize; 2) to determine the nutritional value of decorticated, lime-cooked sorghum; and, 3) to compare the nutritional value of maize and sorghum for use in alkaline-cooked foods.

MATERIALS AND METHODS

Grain Sources

Commercial U.S. no. 2 yellow sorghum classified as Type I (thin red pericarp, intermediate texture, heteroyellow endosperm) and food grade white maize (Asgrow 405 W) were utilized in this study.

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Sorghum was cleaned using a commercial seed cleaner. Five-kilogram batches of whole sorghum were milled for 2 min using the PRL mini dehuller, an abrasive disk decorticator (Reichert 1982). A total of 140 kg of whole sorghum was milled, and the bran was removed using a commercial seed cleaner. The pearled sorghum had some pericarp remaining on some of the kernels. Overall, 10% of the initial weight was removed by the abrasive milling procedures.

Cooking Procedure

Maize and whole and pearled sorghums were cooked in a 110-L steam-jacketed cooker following the procedure outlined in Figure 1 and Table I. Cooking parameters were those determined by Choto et al (1985) to produce tortillas that would have acceptable color and texture. The cooked grains were washed using a shaker-sieving apparatus (Masters Machine Co., Houston, TX), dried using a Wenger drier at an air inlet temperature of 65–70° C, and then ground to pass through a 2-mm screen in a commercial hammer mill (Bell Co., model 20).

Diet Formulation

The experimental diets (Table II) were identical in composition except for the grain source. A small amount (3.25%) of casein was added to provide about 0.4% dietary lysine to ensure adequate feed intake and growth throughout the trial. Chromic oxide was added as a marker for digestibility.

Cannulation and Sample Collection

Seven barrows (average weight of 35 kg) were surgically fitted with a simple T-cannula approximately 15 cm cranial to the ileocecal junction according to the procedure of Horszczauruk et al (1972). After a 15-day convalescence period, five pigs were chosen and placed in individual stainless steel metabolism cages. Pigs were housed under controlled environmental conditions (average temperature of 21 ± 2° C; 50–60% relative humidity, alternating 12-hr periods of light and dark).

The Latin square experiment consisted of five periods, with each period lasting 15 days. Swine were limit-fed daily at 0530 and 1730 hr. Before feeding, diets were mixed with a fixed amount of water to produce a moist mash. The amount fed of each meal approximated 3.5% of the average body weight at the beginning of each period, and intake was kept constant throughout each period. Water was provided ad libitum after each pig had consumed his ration.

Each period began with four days of diet adaptation. Ferric oxide (1% meal) was fed at the morning feeding on days 5 and 10. Total feces collection began when pigs first passed red feces (generally days 6–7) and ended when feces again turned red (generally days 12-13). Urine was collected daily for five days beginning when red feces occurred. Urinary nitrogen losses were prevented by adding 15 ml of concentrated HCl to the urine collection containers. At the conclusion of feces collection, ileal digesta was collected continuously from the morning feeding to the evening feeding (12 hr/day) on three consecutive days. Digesta was collected through polyethylene tubing attached to the open cannula at 15-min intervals, by manually pushing digesta down the tubing into a collection container resting in an ice bath. After the 12-hr collection period, a 200-g aliquot was obtained and frozen. The remaining digesta was warmed to 37° C and returned to the pig via the tubing and cannula.

Daily gains of pigs during the experimental periods averaged 0.58 kg, with an average feed consumption of 1.8 kg/day and feed/gain of 3.3. These data indicate that the cannulation procedure did not severely reduce pig performance.

TABLE I
Cooking Data for Production of Maize, Whole Sorghum, and Pearled Sorghum Products[a]

Parameter	Maize	Whole Sorghum	Pearled Sorghum
H_2O:Grain (weight basis)	3:1	3:1	1.5:1
$Ca(OH)_2$ (% grain weight)	1	0.8	0.2
Cooking time (min)	60	35	5
Steeping time (min)	120	–	–
Washing	+	+	–

[a] Products cooked without lime followed the same procedure except for the deletion of lime.

TABLE II
Percentage Composition of Diets[a]

Item	%
Ground grain	93.79
Casein	3.25
Defluorinated phosphate	1.74
Salt	0.35
Chromic oxide[b]	0.30
Vitamin premix[c]	0.25
Limestone	0.17
Trace mineral premix[d]	0.15
Total	100.00

[a] As-fed basis.
[b] Added as a marker for digestibility.
[c] Contributed the following per kilogram of diet: vitamin A, 4,400 IU; vitamin D, 550 IU; vitamin E, 11 IU; vitamin K, 4.4 mg; riboflavin, 4.4 mg; D-calcium pantothenate, 16.5 mg; niacin, 16.5 mg; choline chloride, 110 mg; and, vitamin B, 10.5 mg.
[d] Contributed the following per kg of diet: Cu, 10 mg; Fe, 100 mg; I, 0.6 mg; Mn, 50 mg; and, Zn, 100 mg.

Chemical Analyses

Ileal and fecal samples were lyophilized and then allowed to equilibrate with the moisture in an air-conditioned room. Samples of the raw and cooked grains, casein, diets, feces, and ileal digesta were analyzed for moisture, ash (AOAC 1976), and nitrogen (Technicon 1976a). The conversion factor 6.25 was used to calculate crude protein values. Diets, feces, and ileal digesta were analyzed for gross energy (Raymond et al 1957) and chromic oxide content (Kimura and Miller 1957); urine was analyzed for nitrogen and gross energy. The raw and cooked grains were further analyzed for ether extract (AOAC 1976), calcium (AOAC 1976), dietary fiber (Asp et al 1983), total and enzyme-susceptible starch (Technicon 1976b), and amino acid content (Spackman et al 1958). Total starch and enzyme-susceptible starch, an index of starch gelatinization, were determined by incubating samples with glucoamylase. The procedures were similar except that samples for total starch were autoclaved for complete starch gelatinization. Amino acid analysis was performed by using a modified Beckman 120 C AA analyzer after 24 hr of hydrolysis in 6*N* HCL.

Composite samples of diet, feces, and ileal digesta of each treatment were prepared by mixing equal amounts of sample from each period. These composite samples were analyzed for dry matter, nitrogen, and amino acid composition with three replicates.

Statistical Analyses

The data were statistically analyzed as a 5 × 5 Latin square. Treatment sums of squares were partitioned into individual degree of freedom contrasts to compare nutritional values of grain sources (maize versus whole sorghum versus pearled sorghum) and the effects of lime cooking (maize and whole sorghum cooked with lime versus maize and whole sorghum cooked without lime versus lime-cooked pearled sorghum) on nutritional values. The general linear model procedure of the SAS Institute (1979) was used for all analyses.

RESULTS AND DISCUSSION

Chemical Composition

The chemical compositions of raw and cooked grains and casein are shown in Table III. Lime treatment and cooking did not greatly affect total crude protein or total amino acid content of the different grains.

Sorghum decortication (10% removal of grain dry weight) decreased the concentration of crude protein, most amino acids, and dietary insoluble fiber. Essential amino acids most affected were isoleucine, lysine, arginine, and leucine, which decreased by 12.5, 14.3, 12.8 and 9.0%, respectively (Table III).

Lime-cooked products had higher ash and calcium contents than the grains cooked without lime. Calcium content of the lime-cooked maize (0.15 g/kg) was similar to that of yellow maize *nixtamal* (0.14 g/kg) reported by Bressani et al (1958). The retention of calcium during lime cooking was 28.3, 33.3, and 47.2% for maize, whole sorghum, and pearled sorghum, respectively. The lower retention values observed for maize and whole sorghum were caused by washing after cooking (Fig. 1).

Cooking reduced insoluble dietary fiber values of maize and whole sorghum because of loss of pericarp tissue during cooking and washing. There was no reduction in value for pearled sorghum. Cooking increased soluble fiber values of all grains. The cooking process probably increased the amount of soluble polysaccharides (gums, pectins, and some hemicellulose) by physical disruption of cell walls.

Among the three types of grains, pearled sorghum had the highest percentage of starch, resulting from the reduction of the dietary fiber, ash, ether extract, and protein fractions caused by the pearling process. Maize and whole sorghum products (raw and cooked) had similar starch and enzyme-susceptible starch (ESS) values. As expected, ESS values increased when the grains were cooked. Lime treatment did not affect the extent of gelatinization (ESS) (Table III).

Lime Treatment

Mean dry matter and gross energy digestibilities for lime-cooked whole sorghum and maize were essentially identical to mean values for the whole sorghum and maize cooked without lime and measured at the terminal ileum (Table IV). Products cooked with and without lime (Table V) had similar (91.1 versus 90.4) total tract gross energy digestibility. Digestible and metabolizable energy (Table VI) were not affected by lime cooking.

In contrast to the effect of lime cooking on energy utilization, nitrogen digestibility was decreased in whole sorghum and maize. Measured near the end of the small intestine, mean nitrogen

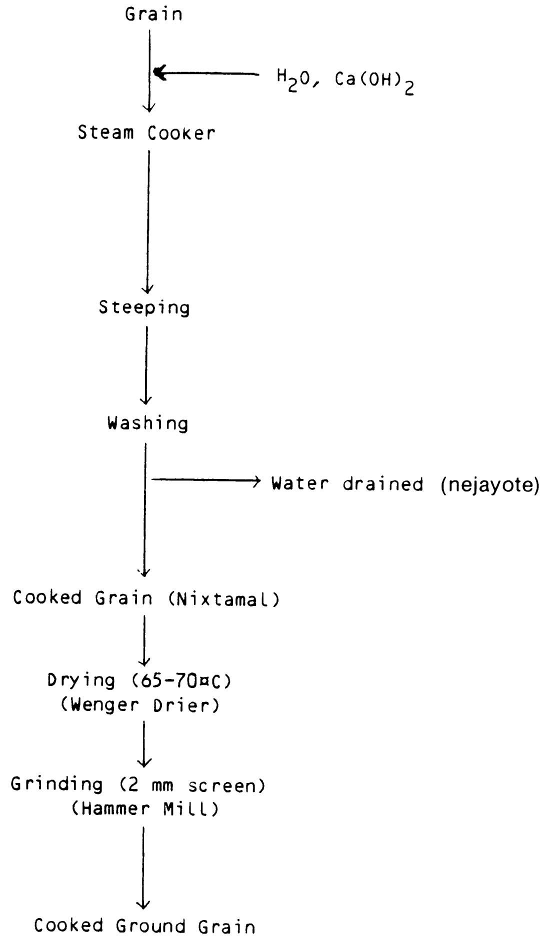

Fig. 1. Procedure to produce maize, whole sorghum, and pearled sorghum products.

TABLE III
Composition of Casein, Raw, and Cooked Grains[a]

Item	Maize			Whole Sorghum			Pearled Sorghum		
	Raw	Cooked w/o Lime	Cooked w/Lime	Raw	Cooked w/o Lime	Cooked w/Lime	Raw	Cooked w/Lime	Casein
Protein, %	10.5	10.4	10.3	10.6	10.7	10.9	10.0	10.2	96.1
Ether extract, %	4.9	4.6	4.6	3.0	3.0	2.9	2.5	2.6	...
Dietary fiber, %									
Insoluble	11.8	10.5	10.5	15.1	14.1	14.0	10.3	10.4	...
Soluble	0.9	1.3	1.3	1.0	1.2	1.1	1.1	1.2	...
Total starch, %	74.0	73.6	73.2	77.9	77.1	77.2	91.8	81.0	...
ESS[b]	100	295	272	199	410	399	166	263	...
Ash, %	1.1	1.1	1.5	1.4	1.1	1.5	1.1	1.1	0.9
Calcium, %	0.02	0.02	0.15	0.02	0.02	0.14	0.01	0.05	
Amino acid,[c] %									
Essential									
Arginine	0.41	0.41	0.42	0.39	0.39	0.40	0.34	0.34	3.16
Histidine	0.21	0.27	0.27	0.22	0.23	0.24	0.21	0.33	2.41
Isoleucine	0.33	0.32	0.33	0.40	0.36	0.36	0.35	0.35	4.53
Leucine	1.25	1.30	1.28	1.34	1.25	1.28	1.22	1.25	8.84
Lysine	0.23	0.23	0.23	0.21	0.21	0.21	0.18	0.18	7.08
Methionine	0.19	0.24	0.25	0.18	0.17	0.15	0.18	0.16	2.76
Phenylalanine	0.50	0.50	0.48	0.52	0.42	0.43	0.49	0.41	4.63
Threonine	0.31	0.31	0.30	0.30	0.29	0.30	0.28	0.27	3.70
Valine	0.45	0.46	0.46	0.50	0.48	0.50	0.47	0.46	6.05
Nonessential									
Alanine	0.70	0.70	0.70	0.83	0.83	0.85	0.81	0.81	2.44
Aspartic acid	0.59	0.55	0.56	0.65	0.56	0.59	0.60	0.56	6.34
Glutamic acid	1.87	1.86	1.86	2.07	1.95	2.01	2.04	1.94	21.70
Glycine	0.29	0.29	0.30	0.28	0.28	0.29	0.26	0.25	1.40
Proline	0.81	0.91	0.90	0.84	0.84	0.84	0.73	0.82	1.40
Serine	0.41	0.42	0.42	0.40	0.40	0.42	0.38	0.38	4.82
Tyrosine	0.39	0.43	0.40	0.39	0.40	0.40	0.37	0.38	5.17

[a] Dry matter basis. Means represent duplicate or triplicate analyses.
[b] Enzyme-susceptible starch, milligrams of glucose per gram of starch.
[c] Condensed weight of amino acids used in calculation percentages.

digestibility was significantly lower ($P < 0.10$) for the lime-cooked whole sorghum and maize, although this difference was small (66.8 versus 65.9% and 76.5 versus 72.8%, respectively) (Table IV). This trend in nitrogen digestibility was not present over the total digestive tract (Table V). The most noteworthy effect of lime cooking was the apparent decreased nitrogen retention (Table VI). Nitrogen retention, expressed as either grams per day, percent of intake, or as a percent of absorbed nitrogen, was consistently lower

TABLE IV
Apparent Digestibilities of Dry Matter, Gross Energy, Nitrogen, and Amino Acids Measured Near the End of the Small Intestine in Pigs[a]

Item	Maize Cooked		Whole Sorghum Cooked		Pearled Sorghum Cooked	Comparison[b]			
	w/o Lime	w/Lime	w/o Lime	w/Lime	w/Lime	1	2	3	4
Dry matter, %	76.3 ± 1.4	76.3 ± 2.9	76.2 ± 2.1	76.8 ± 1.5	80.9 ± 2.6	NS	NS	***	***
Gross energy, %	77.8 ± 1.2	78.4 ± 2.5	77.0 ± 2.0	78.2 ± 1.5	81.9 ± 2.6	NS	NS	***	***
Nitrogen, %									
Individual	76.5 ± 3.7	72.8 ± 5.5	66.8 ± 3.5	65.9 ± 4.8	72.2 ± 3.5	***	**	***	NS
Composite	75.9	72.9	64.5	63.9	73.9				
Amino Acids,[c] %									
Essential									
Arginine	84.0	81.0	77.4	75.5	78.9				
Histidine	82.7	74.9	74.0	68.0	73.3				
Isoleucine	77.8	75.5	70.0	67.6	77.0				
Leucine	84.8	83.3	71.6	71.6	80.4				
Lysine	76.2	70.7	74.6	71.0	75.5				
Methionine	90.9	88.5	77.7	74.6	83.0				
Phenylalanine	84.2	86.2	74.1	78.4	82.7				
Threonine	72.2	67.3	64.0	62.7	70.3				
Valine	80.2	77.7	72.2	71.6	78.1				
Nonessential									
Alanine	77.9	75.4	64.5	67.0	76.2				
Aspartic acid	73.3	70.2	65.9	63.8	73.7				
Glutamic acid	84.9	81.6	74.0	73.7	80.9				
Glycine	53.9	48.4	42.8	52.8	57.6				
Proline	77.9	74.1	62.5	66.3	75.3				
Serine	78.0	71.6	66.4	66.5	74.5				
Tyrosine	80.8	82.9	72.5	71.7	78.8				
Average	78.7	75.6	69.0	68.9	76.0				

[a] Values are means of five observations ± standard deviations.
[b] 1 = Maize with and without lime vs. whole sorghum and without lime. 2 = Maize and whole sorghum with lime vs. maize and whole sorghum without lime. 3 = Pearled sorghum with lime vs. whole sorghum with lime. 4 = Maize with lime vs. pearled sorghum with lime. ** = $P<0.10$; *** = $P<0.01$; and NS = $P>0.10$.
[c] Values are based on analyses of composite samples of diets and ileal digesta.

TABLE V
Apparent Digestibilities of Dry Matter, Gross Energy, Nitrogen, and Amino Acids Measured Over the Total Digestive Tract of Pigs[a]

Item	Maize Cooked		Whole Sorghum Cooked		Pearled Sorghum Cooked	Comparison[b]			
	w/o Lime	w/Lime	w/o Lime	w/Lime	w/Lime	1	2	3	4
Dry matter, %	91.5 ± 1.2	92.0 ± 1.0	89.8 ± 1.3	90.1 ± 0.9	92.7 ± 0.9	***	NS	***	NS
Gross engery, %	91.6 ± 0.9	92.6 ± 1.0	89.2 ± 1.3	89.7 ± 1.4	93.0 ± 1.0	***	**	***	NS
Nitrogen, %									
Individual	85.4 ± 2.4	84.6 ± 3.6	77.6 ± 4.5	79.0 ± 5.4	85.8 ± 3.2	***	NS	***	NS
Composite	87.2	86.9	77.6	80.4	86.1				
Amino acids,[c] %									
Essential									
Arginine	89.7	90.8	83.6	87.7	89.0				
Histidine	91.7	82.3	84.5	84.5	89.5				
Isoleucine	84.4	84.3	76.9	79.8	85.8				
Leucine	91.3	91.3	82.9	86.1	98.5				
Lysine	80.3	80.1	74.5	76.0	81.7				
Methionine	87.1	89.3	76.9	80.9	86.7				
Phenylalanine	90.6	91.4	82.4	85.0	91.0				
Threonine	83.3	83.0	74.9	78.9	83.7				
Valine	86.5	87.2	80.2	83.8	87.5				
Nonessential									
Alanine	86.7	86.8	83.4	83.1	87.8				
Aspartic acid	81.3	82.5	73.9	77.5	83.3				
Glutamic acid	92.5	92.1	85.3	88.0	91.4				
Glycine	80.3	80.1	68.9	73.0	79.6				
Proline	95.1	95.2	87.2	89.7	92.8				
Serine	89.2	87.8	81.1	83.6	88.0				
Tyrosine	87.3	89.6	79.0	83.5	88.0				
Average	87.3	87.7	80.0	82.6	87.3				

[a] Values are means of five observations ± standard deviations.
[b] 1 = Maize with and without lime vs. whole sorghum with and without lime. 2 = Maize and whole sorghum with lime vs. maize and whole sorghum without lime. 3 = Pearled sorghum with lime vs. whole sorghum with lime. 4 = Maize with lime vs. pearled sorghum with lime. ** = $P<0.10$; *** = $P<0.01$; and NS = $P>0.10$.
[c] Values are based on analyses of composite samples of diets and feces.

for the lime-cooked whole sorghum and maize (Table VI). One possible reason for apparent reduction in nitrogen retention expressed as a percent of absorbed nitrogen may be the decrease in ileal lysine digestibility observed in the lime-cooked grains because lysine was probably the limiting amino acid in the diets. Lysine digestibility may have decreased because of formation of lysinoalanine or because of the reaction of lysine's E-amino groups with phenolic acids or reducing sugars (DeGroot and Slump 1969, Chu et al 1976, Sanderson et al 1978). Lime cooking appeared to reduce the digestibilities of other essential amino acids, but the reduction was minimal except for histidine.

The differences in nitrogen and amino acid digestibility present at the end of the small intestine largely disappeared when digestibilities were determined over the total digestive tract (Table V). This suggests that the compounds formed during lime cooking, although indigestible in the small intestine, can be degraded by the micoflora of the large intestine.

In a separate analysis of variance, the interaction of grain source (maize or whole sorghum) and lime cooking was examined. The interaction was nonsignificant ($P = 0.25$) for all variables. This indicated that lime cooking had the same general effect on both whole sorghum and maize. The detrimental effect of lime cooking on protein utilization was greater for maize than for whole sorghum. For example, lime cooking depressed ileal lysine and nitrogen digestibility by 5.5 and 3.7% in maize, but lowered whole sorghum values by only 3.6 and 0.9%, respectively. Nitrogen retention in maize diets was also reduced more by lime cooking. Because both lime concentration and cooking time were greater for maize, it is not possible to determine if these differences were caused by differences in cooking parameters (lime concentration and cooking time) or differences in grain type. Under cooking conditions known to produce consumer-acceptable tortillas, lime cooking does not seem to adversely affect whole sorghum more than maize.

Whole Sorghum Versus Maize

Whole sorghum diets (cooked with or without lime) had significantly lower ($P < 0.01$) dry matter and gross energy digestibilities than the maize diets at both the terminal ileum and over the total digestive tract, as well as lower ($P < 0.01$) digestible and metabolizable energy contents. The higher digestible and metabolizable energy values observed in maize reflected its higher gross energy content. Cousins et al (1981) and Diggs et al (1965) found that raw maize had slightly higher digestible and metabolizable energy values than raw whole sorghum in pigs.

Nitrogen digestibility measured at the end of the small intestine and over the total digestive tract was lower in whole sorghum diets than in maize diets ($P < 0.01$). Nitrogen retention expressed as a percentage of nitrogen intake was also lower ($P < 0.05$) for the whole sorghum diets. In general, the ileal digestibility of the essential amino acids was 5–14% lower for the whole sorghum diets than for the maize diets. The one exception was lysine, which was 1.6% lower for whole sorghum cooked without lime, and 0.3% higher for whole sorghum cooked with lime. Of the measured essential amino acids, threonine was the least digestible and methionine the most digestible for both whole sorghum and maize treatments.

Cousins (1981), in a similar trial, found that ileal digestibilities of lysine were equivalent in raw sorghum (low-tannin, type I) and yellow maize diets containing 6% casein. Tavener et al (1981) found equal ileal lysine digestibilities when raw whole sorghum and yellow maize were compared. In view of the apparent similarity in lysine digestibility found for whole sorghum and maize diets, it is possible that the higher nitrogen retention (as a percentage of nitrogen intake) found for maize mainly reflects the slightly higher lysine content of the maize treatments.

Pearled Sorghum Versus Whole Sorghum and Maize

Lime-cooked pearled sorghum had higher ($P < 0.01$) dry matter, gross energy, and nitrogen digestibilities than lime-cooked whole sorghum measured near the end of the small intestine (Table IV) and over the total digestive tract (Table V). Digestible and metabolizable energy values were also higher for pearled sorghum (Table VI), but the differences were not significant ($P > 0.10$). Nitrogen retention was similar ($P > 0.10$) for lime-cooked pearled sorghum and whole sorghum.

MacLean et al (1982, 1983) showed that decortication and extrusion improved protein and energy utilization of pearled sorghum fed to Peruvian children. The higher insoluble fiber values of whole sorghum (Table III) and the relationship between fiber components and enzyme inhibition could be the reason for the depression in nitrogen digestibility observed in whole sorghum. Several authors (Schneeman and Gallaher 1980, Shah et al 1982, Delorme and Gordon 1983, Fleming and Lee 1983, Ikeda and Kusano 1983) concluded that indigestible polysaccharides (cellulose, hemicellulose, pectins) commonly found in the pericarp inhibit proteolytic enzymes such as trypsin, chymotrypsin, and pepsin, and therefore decrease protein utilization. Zebrowska (1978) suggested that the indigestible cell walls prevent enzymes from entering the cell, thereby decreasing the rate of nutrient digestion.

CONCLUSIONS

A comparison between lime-cooked pearled sorghum and lime-cooked maize showed that the pearled sorghum had equal or better protein and energy digestibilities than lime-cooked maize at the terminal ileum and over the total digestive tract. However, lime-cooked whole sorghum had 90.5% of the ileal nitrogen digestibility of lime-cooked maize. For total tract nitrogen digestibility, the lime-cooked sorghum was 93.3% that of lime-cooked maize. Apparently, some component present in the outer part of the

TABLE VI
Nitrogen Balance, Digestible and Metabolizable Energy Values of Maize, Whole Sorghum, and Pearled Sorghum Diets[a]

	Maize Cooked		Whole Sorghum Cooked		Pearled Sorghum Cooked	Comparison[b]			
Item	w/o Lime	w/Lime	w/o Lime	w/Lime	w/Lime	1	2	3	4
N Intake, g/day	36.1 ± 7.8	36.0 ± 7.9	37.9 ± 8.4	38.2 ± 7.9	36.0 ± 7.4	***	NS	***	NS
Feces N, g/day	4.8 ± 0.9	5.2 ± 1.2	6.7 ± 1.7	6.8 ± 1.5	4.7 ± 1.0	***	NS	*	NS
Absorbed N, g/day	31.3 ± 6.9	30.8 ± 7.5	31.2 ± 8.7	31.4 ± 7.2	31.3 ± 6.8	NS	NS	NS	NS
Urine N, g/day	14.8 ± 4.9	15.9 ± 3.7	15.0 ± 3.0	16.6 ± 3.9	15.9 ± 3.1	NS	*	NS	NS
Retained N, g/day	16.6 ± 4.9	14.8 ± 4.5	16.2 ± 6.1	14.7 ± 3.6	15.4 ± 4.1	NS	NS	NS	NS
Retained N/intake, %	45.8 ± 4.1	41.2 ± 6.6	42.8 ± 7.0	38.6 ± 2.8	42. 8± 3.1	*	*	NS	NS
Retained N/absorbed, %	52.9 ± 4.6	48.2 ± 8.2	52.0 ± 5.5	47.0 ± 2.0	49.2 ± 3.8	NS	*	NS	NS
Digestible energy[c]	4132 ± 49	4141 ± 65	3960 ± 43	3944 ± 39	4031 ± 45	***	NS	NS	***
Metabolizable energy[c]	4027 ± 43	4027 ± 71	3863 ± 32	3890 ± 41	3931 ± 39	***	NS	NS	***

[a] Values are means of five observations ± standard deviations.
[b] 1 = Maize with and without lime vs. whole sorghum with and without lime. 2 = Maize and whole sorghum with lime vs. maize and whole sorghum without lime. 3 = Pearled sorghum with lime vs. whole sorghum with lime. 4 = Maize with lime vs. pearled sorghum with lime. * = $P<0.05$; *** $P=<0.01$; and NS = $P>0.10$.
[c] kcal/kg of dry matter.

sorghum kernel causes a decrease in nitrogen digestibility. The component is apparently reduced when the sorghum is pearled. Based on these data, pearled sorghum has certain advantages in comparison to maize: it requires one-tenth of the cooking time and lower lime concentration; it has equal or better protein and energy digestibilities and similar nitrogen retention. However, decortication reduces the total protein and essential amino acid content. Lime-cooked whole sorghum has about 5–6% lower protein digestibility than lime-cooked maize. Thus, the substitution of sorghum for all or part of the maize in tortillas and other human foods should not seriously affect the nutritional status of most consumers. However, for certain groups that have marginal levels of protein in the diet, sorghum would not be as desirable.

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