APPENDIX V

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The Effect of Decortication and Extrusion on the Digestibility of Sorghum by Pre-School Children

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ABSTRACT

The effect of decortication and extrusion on the apparent protein quality and digestibility of sorghum (S. vulgare) was evaluated in comparative balance studies in 9 children 7 to 24 months of age. Sorghum provided 8% protein kcal and 62% carbohydrate kcal in the study diet. Lysine was supplemented to 3% of protein. Casein provided 6.4% protein kcal in the control diet. A mixture of sucrose, dextrimaltose and corn starch provided carbohydrate. Both diets contained 30% fat kcal as soybean-cottonseed oil blend. Balance studies were carried out during the last 6 days of 3 9-day dietary periods: control-sorghum-control. Apparent N absorption from sorghum was 81±4% and did not differ from control. Apparent N retention, 21±6%, was expectedly lower than the preceeding control (27±8%, $P<0.05$) and following control (33±7%, $P<0.01$) values. The control values differed significantly from each other ($P<0.05$). Fecal weights and energy losses showed only minor differences between the two diets. These data contrast sharply with previous results obtained with whole grain sorghum and suggest that the use of decortication and low-cost extrusion processing can markedly improve the apparent protein quality and digestibility of sorghum.

Key words: protein sorghum infant nutrition extrusion milling

Sorghum is widely consumed in the developing nations of Africa and Asia. Because this cereal grows well in arid regions unsuitable for the cultivation of other crops, it remains a staple food for many of the worlds poor. Production has increased substantially over the past three decades: between 1952 and 1968, world-wide acreage planted with sorghum increased over 1200% and per acre yield rose 80% (1). This trend is expected to continue, aided in large part by the research and programatic efforts of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and the International Sorghum and Millet collaborative research program (INTSORMIL) in the United States.

Feeding the weaned infant remains the single most difficult nutritional problem facing the developing nations. Infants and small children have the highest nutrient requirements, because of their rapid growth, and the least well developed digestive capabilities. Our previous studies of four varieties of sorghum, including two high lysine (3% of protein) varieties, showed that whole grain sorghum flour was unsuitable for infants and small children, owing primarily to its poor digestibility (2). Poor digestibility appeared to account for the poor nitrogen utilization that was encountered. No difference could be detected between high-lysine and conventional varieties in those studies. Fecal energy losses averaged 21% of energy intake and together with the low quality of the protein in sorghum seemed to explain adequately the near cessation of weight gain that occurred in the children participating in the studies.

Although many countries consume traditional dishes based on whole grain sorghum, there are many other ways of preparing sorghum that depend on decorticated grain (3). Fermentation is also used in some instances. These traditional methods of processing have probably evolved because they improve taste and, very possibly, digestibility. This is suggested by the practice in some countries of preferentially feeding sorghum prepared by more extensive "processing" to small children or sick adults.

The current studies were undertaken to ascertain the degree to which milling and processing could improve digestibility of sorghum and to confirm that digestibility was the factor primarily limiting nitrogen utilization. Because of the good results obtained previously with extruded blends that contained sorghum (4) we chose to study a decorticated, extruded sorghum flour.

MATERIALS AND METHODS

This was a comparative balance study in which each child consumed both the study and control diets. Metabolic balance studies were carried out during the last 6 days of each of 3 dietary periods: initial control, study and subsequent control. The protocol paralleled that used in previous studies of sorghum from our unit (2).

Subjects. Nine Peruvian mestizo children participated in the studies with the informed consent of their parents.[2] All were males who had been admitted to the Instituto de Investigacion Nutricional (Nutrition

Research Institute) in Lima, Peru, for the treatment of acute and chronic malnutrition. At admission, four children were diagnosed as marasmus, three as marasmic kwashiorkor, and two as kwashiorkor, using the McLaren Score (5). At the time of entrance into the study all were well past the acute phases of treatment and were remaining in hospital for long term recuperation and dietary therapy. There was still significant stunting and wasting at this time. Mean (range) age, height age, and weight age were 14.0 (7-24) months, 6.3 (2.9-13.3) months, and 3.9 (1.1-11.5) months, respectively. Mean (range) serum albumin concentration was 3.84 (3.31-4.25) g/dl. All children were gaining weight, were free of infection, and had no significant degree of malabsorption based on preliminary balance data at the time the studies began. More complete data on individual children are found in Table 1.

Diets. A single variety of sorghum was studied. This variety, 954063, was one of four varieties used in previous studies of the nutritional value of whole grain sorghum (2). This sorghum was decorticated in the Carlsberg Research Laboratory, Copenhagen, Denmark, and then extruded at Colorado State University at low moisture content in a Brady extruder at 350^{0} with a throughput of 345 kg/hr.

The proximate analysis of the resulting product is shown in Table 2. In comparison to the whole grain product used in our previous studies, the pearled and heat-extruded product was slightly (4%) higher in nitrogen content but 24% lower in lysine concentration (1.6 g/100 g vs 2.1 g/100 g). Fat content was substantially lower (0.15 g/100 g vs 3.15 g/100 g) and carbohydrate content slightly (12%) higher.

A sorghum-based study diet was designed in which protein (Nx6.25) provided 8% of dietary energy (Table 3). Lysine, the first limiting amino acid in sorghum relative to the FAO/WHO reference pattern (6), was supplemented to a level of 3% of protein, the lysine level of currently available high-lysine varieties of sorghum. A blend (80:20) of soybean and cottonseed oils was used to provide 29% of energy in the diet. Carbohydrate from the sorghum provided the remaining 63% of energy. The sorghum diet was prepared by boiling the sorghum until gelatinization occurred (approximately 10-15 minutes) and then blending this with the other ingredients and water to produce a liquid formula diet whose concentration was approximately 0.67 kcal/ml. The diet was fed by bottle.

The control diet used casein[3] as its protein, which provided 6.4% of dietary energy. The soybean-cottonseed oil blend provided 30% of energy. Carbohydrate was supplied by a mixture of sucrose, dextrimaltose, and corn starch in nearly equal amounts. Although it might have been theoretically preferable to use starch as the sole source of carbohydrate in the control diet, it is not possible to produce a liquid diet using these quantities of starch. The control diet was also prepared in blenderized liquid form.

Both diets provided 2 mEq Na/100 kcal and 3 mEq K/100 kcal and were approximately equal in other major mineral contents. All vitamins and trace elements were supplemented to meet or exceed U.S. Recommended Dietary Allowances (7) using vitamin and mineral mixtures standard for the unit.[4] All children consumed between 80 and 130 kcal/kg body wt/day. Intake was constant throughout the study for each child and was

recalculated at the beginning of each dietary period. Diets were analyzed regularly for energy, nitrogen, sodium and potassium to assure that actual intakes were as calculated.

Protocol. Each study comprised three dietary periods of 9 days each. A sorghum dietary period was preceeded and followed by a control dietary period. After three days of adaptation to each diet, the child was placed in a metabolic bed for six days for complete collection of urine and stool. Blood was obtained on the first day of the study and at the end of each dietary period for the determination of hematocrit, serum total protein (Biuret) and albumin (acetate gel electrophoresis) concentrations.

All stools were weighed wet and after drying. Fecal and urinary nitrogen concentrations were determined in three-day pooled collections by the micro-Kjeldahl method (8). Fecal fat was determined by the method of Van de Kamer and associates (9). Energy intake and fecal energy losses were determined by bomb calorimetry (10).

Apparent absorptions and retentions of nitrogen were calculated. These and other data from sorghum dietary periods were compared to values for both control periods using t tests for paired data (11). Data from both the initial and subsequent control periods were compared in the same manner.

RESULTS

Results of balance studies are summarized in Table 4. Rates of weight gain were similar for all dietary periods. Apparent absorption of nitrogen from the sorghum diet did not differ from values for the two control periods. In contrast, apparent retention of nitrogen from sorghum, 21±6%, was significantly less than that during either of the two control dietary periods (preceeding: 27±8%, $P<0.05$; subsequent: 33±7%, $P<0.001$). Apparent nitrogen retention was significantly ($P<0.05$) higher during the final control period than during the initial control period.

There were small, and sometimes statistically significant, differences among values for stool wet weight and dry weight, fecal fat, and fecal energy loss. None of these differences was of a magnitude considered to be of nutritional significance. Serum albumin concentration fell slightly during both the initial control period (Δ = -0.17±0.25 g/dl) and the sorghum dietary period (Δ =-0.24±0.41 g/dl), and then increased minimally during the final control period (Δ =0.14±0.37 g/dl). Only the decrement during the sorghum dietary period was statistically significant ($P<0.05$).

DISCUSSION

The results of these studies clearly indicate that the digestibility of sorghum can be markedly improved by processing, in this case a

combination of milling and extrusion cooking. The decision both to mill and to extrude the sorghum for these studies was based on a desire to improve as much as possible the poor digestibility of whole grain sorghum. While it would have been preferable to run additional dietary groups with decorticated sorghum not subjected to extrusion and with extruded whole grain sorghum, those "intermediate" studies could not be justified in the human, based on our previous experience with sorghum, until it could be shown that a combination of the two processes significantly altered digestibility. Cost was also a constraint.

None of the parameters indicative of digestibility showed a major difference from the highly processed control diet. Apparent absorption of nitrogen from the sorghum diet did not differ from that from the control diet. Stool weights and energy losses were slightly higher but not unexpectedly so for a cereal-based diet.

All of these digestibility data are in marked contrast to results from previous studies using whole grain sorghum (Table 5) (2). The current results represent an increase of 76% in apparent nitrogen absorption, and decreases of 280% in stool wet weight, 173% in stool dry weight, and 144% in fecal energy loss, compared to previous studies of sorghum; they are equal to those obtained in previous similar studies of wheat noodles (12), and superior to those for milled rice (13), maize (14), and potato (15).

Apparent nitrogen retention from sorghum was expectedly inferior to that from casein. This was clear both in the comparison of the values for sorghum to those from each of the control dietary periods and in the

comparison of data from both control periods with each other. The significantly greater apparent retention in the final control period compared to the initial control period represents an attempt to compensate for the inadequate retention of nitrogen from sorghum and has been seen in previous studies. Clearly the poorer retention of nitrogen could not be explained adequately on the basis of poor digestibility, as it had been in our initial studies.

Availability of lysine may have continued to be the primary factor despite the (presumable) 80% availability of the lysine in sorghum protein and the fact that 47% of the lysine in the diet was supplied from the supplement as lysine hydrochloride. Threonine may also have been inadequate. Daniel et al (16) have shown a beneficial effect on apparent nitrogen retention of threonine and lysine supplementation over that obtained by supplementation of lysine alone.

With lysine supplementation, apparent protein quality of sorghum was similar to that for unsupplemented wheat, in which lysine supplementation markedly improves nitrogen retention (17). Nitrogen retention was lower than we have previously reported for rice (mean apparent N retention 26%) (13) and whole kernel sugary 2-opaque 2 maize meal (mean apparent N retention 37%) (14), in both of which lysine is the first limiting essential amino acid. Apparent nitrogen retention from potato, in which methionine is limiting, was also higher, 34% (15).

Our results parallel previous data with an extruded blend of 80% wheat-soy and 20% dehulled sorghum (Thriposha) (4) and suggest that this low cost, easily transferrable technology (18) could markedly increase

the net nutritional "yield" from sorghum. Because of the lower lysine concentration of the decorticated-extruded product (presumably due to milling) lysine supplementation either at the time of processing or through dietary complementation is necessary to assure maximum nitrogen utilization. Even without lysine supplementation, sorghum processed in this fashion can provide a significant percentage of dietary energy (>70% in these studies) without any adverse effect on stool output. The effect of such diets on the bioavailability of trace elements, however, is unstudied.

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Footnotes

1 Supported by research contract AID/ta-C-1286 with the Agency for International Development, U.S. Department of State and by grant HD 10111 from the National Institutes of Health, USPHS.

2 The protocol for these studies was approved by the Committee on Human Subjects of the Instituto de Investigacion Nutricional, Lima, and the Joint Committee on Human Investigation, School of Medicine, the Johns Hopkins University, Baltimore.

3 Casec® (Mead-Johnson)

4 Provided by Mead-Johnson and Company, Evansville, IN 47721.

Table 1: Descriptive data on children participating in the studies

Patient No.	Diagnosis[1]	Hospital Day	Age mos.	Height cm	Height Age[2] mos.	Weight kg	Weight Age[2] mos.	(Alb) g/dl
662	M	38	14	69.7	8.0	5.94	3.4	3.90
672	M	56	9	62.4	3.8	5.00	1.7	4.25
673	M	61	18	72.0	8.8	8.20	6.8	3.87
678	M	47	7	60.9	2.9	4.97	1.7	3.50
685	MK	57	7	61.4	3.1	4.41	1.1	3.95
686	MK	86	17	65.8	4.9	5.18	2.0	3.95
690	K	41	18	68.5	6.5	6.67	4.0	3.86
692	MK	39	12	66.5	5.3	5.57	2.5	3.31
694	K	49	24	77.6	13.3	10.04	11.5	3.96

[1] Based on the McLaren score (5).

[2] Calculated using the median of the NCHS reference data ( ).

Table 2: Proximate analysis of the sorghum used in these studies. All values per 100 g except lysine.[1]

Nitrogen - mg	1698.4
Protein (Nx6.25) - g	10.62
Lysine - g/100 g protein	1.58
Fat - g	0.15
Ash - g	0.40
Fiber - g	1.55
Carbohydrate[2] - g	83.68
Moisture - g	3.60
Energy[3] - kcal	379

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1 Analysis of nitrogen was carried out in the Instituto de Investigacion Nutricional. Lysine content was determined in the Department of Agronomy, Purdue University. All other analyses were done by the Food Analysis Laboratory of the Department of Nutrition, Universidad Nacional Agraria, La Molina (Lima) Peru.

2 Calculated by difference.

3 Calculated using Atwater's values for protein, fat, carbohydrate.

Table 3: Composition of the sorghum and control diets per 100 kcal[1]

	Sorghum	Control
Sorghum - g	18.84	--
Lysine - mg	39.68	--
Soybean-Cottonseed (80:20) oil - ml	3.62	3.67
Sucrose - g	--	5.81
Dextrimaltose - g	--	6.00
Corn starch - g	--	5.00
Casec®[2] - g	--	1.86
Calorie Distribution		
Protein - %	8.0	6.4
Fat - %	29.0	30.0
Carbohydrate - %	63.0	63.6

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1 All diets were supplemented with a vitamin and trace mineral mixture of the following composition to meet or exceed Recommended Dietary Allowances (7) (% wt/wt): NaCl, 30.701; $MgSO_4$ $7H_2O$, 22.804; $CaHPO_4$, 41.615; $FeC_6H_5O_7 \cdot 3H_2O$, 3.549; $CuSO_4 \cdot 5H_2O$, 0.625; $ZnSO_4 \cdot 7H_2O$, 0.355; $MnSO_4 \cdot H_2O$, 0.277; KI, 0.025 and NaF, 0.50.

Vitamins were supplemented by a single daily dose of 0.6-1.2 ml of Poly-Vi-Sol (Mead Johnson, Evansville, IN). The composition (per ml) of this preparation is as follows: retinyl palmitate, 1,500 IU; ergocalciferol, 400 IU; Vitamin E, 5 IU; ascorbic acid, 35 mg; thiamin, 0.5 mg; riboflavin, 0.6 mg; niacin, 8 mg; vitamin B_6, 0.4 mg, and vitamin B_{12}, 1 ug. Patients also received a single dose of 101 mg choline, 180 mg myo-inositol, 200 ug folic acid and 500 mg PABA.

2 Casec® (Mead-Johnson): 1 g provides 0.86 g protein, 0.02 g fat, and 3.70 kcal.

Table 4: Summary of balance studies with heat extruded milled sorghum.

Diet	n	Δ wt	Nitrogen Abs	Nitrogen Ret	Stool Weight Wet	Stool Weight Dry	Stool Fat	Stool Fat % of intake	Stool Energy % of intake	Serum Albumin Final	Serum Albumin Δ
		g/kg/d	%	%	g/d	g/d	g/d	%	%	g/dl	g/dl
Casein (pre)	9	4.3	84	27[d]	46	11.6[e]	2.6	12	6.9	3.71	-0.17
		±1.8	±3	±8	±12	1.7	±0.5	±3	±0.9	±0.34	±0.25
Sorghum	9	3.3	81	21[a,f]	59	14.3[b]	1.6	7[c,f]	8.6[b,e]	3.47[a]	-0.24
		±1.4	±4.0	±6	±15	±1.8	0.6	±3	±1.9	±0.20	±0.41
Casein (post)	9	4.1	82	33	57	12.8	2.9	11	6.9	3.61	0.14
		±1.8	±4	±7	±13	±1.6	±1.0	±3	±1.3	±0.33	±0.37

[a] Differs from corresponding value of preceeding control period, $P<0.05$
[b] Differs from corresponding value of preceeding control period, $P<0.01$
[c] Differs from corresponding value of preceeding control period, $P<0.001$
[d] Differs from corresponding value of subsequent control period, $P<0.05$
[e] Differs from corresponding value of subsequent control period, $P<0.01$
[f] Differs from corresponding value of subsequent control period, $P<0.001$

Corresponding values without superscripts did not differ significantly.

Table 5: Comparison of results of current studies with those of previous studies of ground whole grain.

		Nitrogen		Stool			
				Weight		Fat	Energy
	n	Abs	Ret	Wet	Dry	% of intake	% of intake
		%	%	g/d	g/d	%	%
Sorghum --							
pearled, extruded	9	81	21	59	14.3	7	8.6
(current studies)		±4	±6	±15	±1.8	±3	±1.9
Sorghum --							
whole grain,	26	46	14	224	39.0	15	21.0
ground		±17	±10	±66	±11.8	±12	±13.5
(previous studies)(2)							