Production and Nutritional Evaluation of Liquefied Weaning Foods from Malted Sorghum, Quality Protein Maize, and Other Cereals

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Cereal Chem. 77(5):652–656

ABSTRACT

Different concentrations of sorghum diastatic malt (SDM) were added to pregelatinized pastes from regular maize flour with the aim of hydrolyzing the starch to produce liquefied foods with 15% solids. Viscosities of the blends decreased as the concentration of SDM increased. Addition of 6.66% SDM based on total amount of solids reduced viscosity by ≈50% when compared with a food that did not contain any SDM. Addition of 33.3 or 46.6% SDM reduced viscosity by ≈70 or 75%, respectively. Most of the reduction in viscosity occurred within 1–3 min of incubation with warm water. Weanling rats were fed a combination 33.3% SDM and 66.6% of either quality protein maize (QPM), regular maize (RMZ) or decorticated pearl millet (DPM) to estimate protein efficiency ratios (PER), protein digestibility, biological value (BV), and net protein utilization (NPU). Rat growth was positively correlated with dietary lysine content and essential amino acid (EAA) scores; therefore, animals fed QPM weaning food had significantly higher ($P < 0.05$) protein digestibility corrected EAA scores, PER, BV, and NPU than counterparts fed diets based on RMZ or DPM. This demonstrates that it is feasible to produce nutritious liquefied weaning foods blending 33.3% SDM with 66.6% QPM using simple processing techniques.

There were ≈5.9 billion people inhabiting the word in 1998 with at least 1 billion suffering from *Kwashiorkor*, *Marasmus* and other related malnutrition problems (Onuma Okezie 1998; FAOSTAT 1999 http//apps.fao.org/). Of the people inhabiting developing countries, ≈20% are chronically malnourished (Onuma Okezie 1988). Most of these problems occur in individuals who only consume cereal grains, tubers, or starchy foods and do not have access to enough legumes and animal foods. In underdeveloped countries in Asia, Africa, and Latin America, the most prevalent cause of death in postweaned infants is protein malnutrition or *Kwashiorkor.* More than 12 million children under age 5 died annually because of food-related nutrition and health conditions (Onuma Okezie 1998). The most common weaning foods used to feed infants in underdeveloped countries are starchy gruels produced from traditionally refined cereal grains or tubers. The production and nutritional quality of weaning foods prepared by traditional methods have been reported by several authors (Ahmed et al 1981, Mosha and Svanberg 1983, Okeiyi and Futrell 1983, Griffith et al 1998, Marero et al 1988, Almeida Dominguez et al 1993). The main problems associated with starchy foods are the lack of adequate protein quality or essential amino acids and the high viscosity that limits intake, especially in weaned infants. Production of liquefied foods can be achieved using malted cereals or commercial amylolitic enzymes (Desikachar and Malleshi 1982, Mosha and Svanberg 1983, Marero et al 1988, Chavan and Kadam 1989, Pedersen et al 1989, Gopaldas et al 1991, Kulkani et al 1991). The α- and β-amylases synthesized during germination break down gelatinized starch, producing a liquefied drinkable food. Furthermore, other enzymes such as proteases and phytases increase protein digestibility and mineral bioavailability (Wang and Fields 1978, Chavan and Kadam 1989). The caloric density must be sufficient and meet requirements of essential nutrients for the growing infant.

In Africa, sorghum is often malted to produce a wide array of traditional foods although its utilization for the production of weaning foods is limited or nonexistent. The recent development of new QPM cultivars or hybrids with enhanced nutritional value is now a reality in Ghana, South Africa, Brazil, China, and many other countries around the world (Larkins and Mertz 1994). QPM-based foods have almost twice as much lysine and tryptophan as regular maize (Gupta et al 1979, Sproule et al 1988, Graham et al 1990, Villegas et al 1992).

In this experiment, different concentrations of sorghum diastatic malt (SDM) were tested to produce liquefied weaning foods from regular maize (RMZ), quality protein maize (QPM), or decorticated pearl millet (DPM). The nutritional value and protein qualities of weaning foods produced blending 33.3% SDM and 66.6% of the other cereal sources were compared using laboratory rats.

MATERIALS AND METHODS

Grains

White QPM and regular maize were grown at Apodaca, NL, México, during the 1996 early corn season. The QPM was an experimental hybrid developed at Texas A&M University; the regular maize was a local synthetic cultivar (NLVS-CIMMyT). The grain weights QPM and regular maize were both 89.5 kg/hL; 1,000 kernel weight values of QPM and regular maize were 231.6 and 374 g, respectively. Sorghum and pearl millet were obtained from the Cereal Quality Laboratory at Texas A&M University. A white sorghum (ATX631 × RTX436) with good malting properties had a moisture content of 10.9%, weight of 78.9 kg/hL, and 1,000 kernel weight of 28.7 g. The pearl millet was a commercial cultivar with a moisture content of 8.9%, weight of 92 kg/hL, and 1,000 kernel weight of 8.7 g. The pearl millet was decorticated to remove ≈25% of its weight using a mill from International Development Research Centre (IDRC), Ottawa, ON, Canada, equipped with eight abrasive disks (24 cm diam). Decorticated grains were separated from bran and germ with a laboratory seed cleaner (model 400-1, Seedburo Equipment Co., Chicago, IL) equipped with 1/15 (2 mm) and 6 (3 mm) sieves. All grains were ground in a Wiley mill (model 3, Philadelphia, PA) first to pass through a 2-mm sieve and then through a 1-mm sieve.

Sorghum Malting

Lots of sorghum (1 kg) were soaked for 24 hr under aeration in 3 L of water containing 0.01% (v/v) formaldehyde. The steep water was eliminated, and hydrated grains were soaked and washed with a 2% (v/v) chlorine solution for 10 min and then rinsed with distilled water. Grains were placed on germination trays and placed in a germinator (model D7440, Seedburo) set at 28°C for 108 hr. During germination, grains were agitated every 12 hr. The resulting sorghum malt was dried in a forced-air oven (Electrolux) set at 44°C for 48 hr. The dehydrated malt was ground in a Chopin roller mill by grinding two and five times through the set of break and

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Publication no. C-2000-0817-04R.

reduction rolls, respectively. All fractions were homogenized, packaged in polyethylene bags, sealed, and stored in a freezer at –2°C. The diastatic activity of sorghum malt was determined after obtaining a NaCl (0.5%, w/v) extract that hydrolyzed starch under controlled conditions (AACC 2000). The alkaline ferricyanide method and titration with sodium thiosulfate (AACC 2000) determined the amount of reducing sugars.

Chemical Composition

Proximate analysis. Grains and weaning foods were analyzed for moisture, protein (N × 6.25), ash, crude fiber, and ether extract (AOAC 1990). The nitrogen free extract (NFE) was calculated by difference (100 – % moisture – % protein – % crude fiber – % ash – % ether extract).

Calculated digestible energy. The digestible energy value of the weaning foods was calculated using values of 4 kcal/g of protein, 4 kcal/g of NFE or carbohydrates and 9 kcal/g of fat (Livesey 1995).

Amino acid composition. The amino acid composition, except tryptophan and sulfur, was determined in samples hydrolyzed with 6*N* HCl. For amino acids containing tryptophan and sulfur, samples were hydrolyzed with 3*N* 2-N-morpholino ethanesulfonic acid (MES) and performic acid, respectively. All amino acids were diluted with buffers and quantified by reaction with ninhydrin using HPLC (Beckman 6300). Amino acid data was used to calculate essential amino acid (EAA) scores by dividing the quantity of the limiting EAA by the corresponding requirement for a 2-year-old infant (FAO/WHO 1990).

TABLE I
Diet Composition for Rat Bioassays[a]

	RMZ	QPM	DPM	Control
Content				
Ground grain[b] (%)	92.7	92.7	78.4	…
Starch[c] (%)	0.0	0.0	12.7	75.7
Casein[d] (%)	…	…	…	7.8
Corn oil (%)	2.7	2.4	3.6	6.0
Minerals[e] (%)	3.5	3.5	3.5	3.5
Vitamins[f] (%)	1.0	1.0	1.0	1.0
Cellulose[g] (%)	0.18	0.32	0.8	1.0
Total	100.0	100.0	100.0	100.0
Composition[h]				
Moisture (%)	9.72	9.61	9.40	9.24
Protein (%)	8.95	7.19	9.33	9.54
Ether extract (%)	4.78	4.82	4.35	4.48
Ash (%)	4.24	4.16	3.65	3.54
Crude fiber (%)	0.99	0.89	0.71	0.65
NFE (%)	81.0	82.9	82.0	81.8
Digestible energy, kcal/100 g	402.8	403.7	404.5	405.7

[a] Regular maize diet (RMZ), quality protein maize diet (QPM), decorticated pearl millet diet (DPM), and control casein diet.
[b] Cereal-based diets contained 66.66% of the cereal plus 33.33% of sorghum diastatic malt (SDM).
[c] Maizena.
[d] AIN casein purified high nitrogen. ICN Biomedicals, Inc.
[e] AIN 76 mineral mixture. ICN Biomedicals, Inc. (g/kg).
[f] AIN vitamin mixture 76. ICN Biomedicals, Inc.
[g] AIN alphacel nonnutritive bulk. ICN Biomedicals, Inc.
[h] Results expressed on dry matter basis (*n* = 2).

TABLE II
Chemical Composition of Sorghum Malt and Grains Used to Produce Liquefied Weaning Foods[a]

	RMZ	QPM	DPM	Grain	SDM
Moisture (%)	8.39	8.67	9.12	9.05	4.93
Protein (N × 6.25)	7.76	7.76	9.96	8.42	8.39
Ash (%)	1.40	1.40	1.14	1.48	1.42
Ether extract (%)	4.84	5.29	3.91	2.52	2.31
Crude fiber (%)	1.08	0.81	0.13	0.86	0.82
NFE[b] (%)	84.9	84.7	85.0	86.7	87.06
Digestible energy,[c] kcal/100 g	414.2	417.6	415.0	410.2	402.6

[a] Quality protein maize (QPM), regular maize (RMZ), decorticated pearl millet (DPM), sorghum grain (Grain), and sorghum diastatic malt (SDM). Results are expressed on dry matter basis (*n* = 2).
[b] Nitrogen free extract.
[c] Calculated digestible energy.

Production and Viscosity of Liquefied Foods

Weaning foods (15% solids) were produced by mixing different concentrations of SDM (0, 6.66, 13.3, 20, 33.3, 46.6%) and RMZ flour. The viscosity of resulting mixes were determined with a viscometer (Brookfield DV) equipped with a No. 1 needle. Tests were conducted at 100 rpm and 40 ± 2% torque. Water heated to 100°C was blended with RMZ flour and blended for 2 min at low speed in a laboratory blender (commercial model 31BL91, Waring) to gelatinize the starch. SDM was mixed with the gelatinized paste when the temperature dropped to 50°C and immediately placed in a water bath set at 45°C. After 15 sec of agitation, viscosity measurements were made every minute for the first 10 min and every 5 min thereafter until completion at 30 min.

Rat Feeding Studies

Protein efficiency ratios (PER). Four different treatments were tested, three were weanling foods produced from a combination of 66.66% RMZ, QPM, or DPM with 33.33% SDM; the fourth consisted of a control casein diet (Table I). Four male and four female weanling rats per treatment were housed individually for 35 days in stainless steel wire-bottomed cages under controlled environmental conditions (21°C) and alternating 12-hr periods of artificial light and darkness. The 21 ± 2 day-old rats were blocked by initial weight and sex and randomly assigned to the four treatments. Animals were fed isonitrogenous and isocaloric diets formulated according to standard procedures (AOAC 1990). The control diet was formulated to have the same amounts of crude fiber, ether extract, and protein as the experimental diets, and contained high nitrogen casein (ICN Pharmaceuticals, Inc.) (Costa Mesa, CA) as the sole source of protein. Rats were fed ad libitum; weight gains and feed intake were recorded weekly. Final PER values were adjusted according to the PER of the control casein group.

Metabolic study. During the third and fourth week of the PER experiment, feces and urine were collected daily for each rat. Feces and urine were pooled and stored in a freezer. Urinary nitrogen losses were prevented by adding 1 mL of HCL (1:1) to the collection containers daily. The composite urine sample was filtered through Whatman No. 1 paper then diluted to 65 mL with distilled water and assayed for nitrogen (AOAC 1990). Feces were dehydrated at 55°C for 20 hr, cleaned, weighed, and analyzed for moisture and nitrogen (AOAC 1990). Digestibilities and nitrogen retention values were calculated as:

$$\text{Apparent protein digestibility} = [\text{feed intake } (\%\text{ N feed}) - \text{feces } (\%\text{ N feces})] / \text{feed intake } (\%\text{ N feed}) \times 100$$

$$\text{Biological value (BV)} = [\text{feed intake } (\%\text{N feed}) - \text{feces } (\%\text{ N feces}) - \text{urine } (\%\text{ N urine})] / (\text{Feed intake } (\%\text{N feed}) - \text{feces } (\%\text{ N feces}) \times 100$$

$$\text{Net protein utilization value (NPU)} = (\%\text{ protein digestibility}) (\%\text{ BV})/100$$

Protein digestibility corrected EAA scores (PDCEAAS) were obtained by multiplying the EAA score by the corresponding apparent protein digestibility: PDCEAAS = (EAA Score) (Apparent Protein Digestibility)/100.

Statistical Analyses

The nutritional data was statistically analyzed using analysis of variance procedures in a split plot and a complete randomized block design where sex was the whole plot and initial weight the subplot. Minimum significant differences (MSD) between and among treatments means were calculated. In addition, correlations among nutritional variables were determined. All statistical analyses were performed using established procedures (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Chemical Composition

The protein (N × 6.25) content of RMZ and QPM were similar and in the lower range expected for maize (Sproule et al 1988, Serna Saldivar et al 1991). DPM had the highest protein content despite being decorticated and had partial losses of protein rich germ tissue (Table II). However, the protein content of DPM was slightly lower when compared with the amounts reported by other authors (Serna Saldivar et al 1991, 1994; Almeida Dominguez et al 1994). As expected, DPM contained the lowest levels of ash and crude fiber. However, decortication did not decrease ether extract levels to the desirable extent. Removal of the fiber-rich pericarp tissue was very effective because the decorticated grain had very low levels of crude fiber and only 1.1% ash (Table II). However, decortication of pearl millet to remove 25% of its weight was not enough to completely remove the germ. Among cereals, pearl millet contains one of the highest proportions of germ to endosperm, thus it has one of the highest oil levels of the cereal grains (Serna Saldivar et al 1992). Processing sorghum into diastatic malt slightly reduced ash, ether extract, and crude fiber contents. During germination, stored lipids, proteins, and starch are enzymatically broken down yielding simpler compounds such as free fatty acids, peptides, and dextrins and reducing sugars. Some of these compounds are broken down into carbon dioxide. Almeida et al (1994) also reported slight losses of lipids and fiber during sorghum malting. Germination of sorghum for 108 hr at 28°C produced malt with 117.3 diastatic units/g. This diastatic power is considered high when compared with other sorghum malts and ≈33% lower when compared with commercial barley malt.

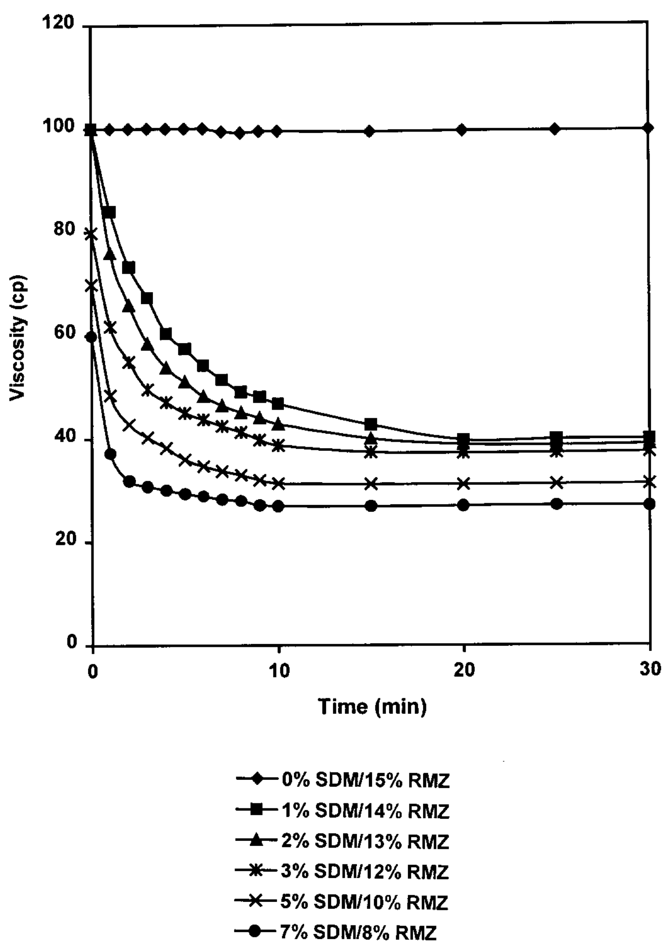

Fig. 1. Effect of different concentrations of diastatic sorghum malt on the viscosity of regular maize pastes incubated for different times. SDM = sorghum diastatic malt, RMZ = regular maize flour. All weaning foods contained a total of 15% solids.

Production of Liquefied Weaning Foods

As expected, addition of RMZ flour to boiling water increased viscosity due to starch gelatinization. Addition of different amounts of SDM to the resulting pastes incubated at 45°C rapidly reduced viscosity. The reduction was related to both SDM concentration and exposure time (Fig. 1). Increasing SDM concentration and hydrolysis time decreased viscosity. Some liquefied mixes had 25% of the viscosity observed in the control untreated pastes. The α- and β-amylases developed during sorghum germination hydrolyzed starch molecules, yielding dextrins and fermentable carbohydrates (Hansen et al 1989, Kulkani et al 1991, Almeida Dominguez et al 1993, Beta et al 1995). Addition of 1, 2, 3, and 5% SDM to the 15% total solid SDM-RMZ blend caused a 50% reduction in viscosity after 8, 5, 3 and 1 min, respectively (Fig. 1). The most important reduction in viscosity was observed during the first 3 min after addition of SDM. The reduction reached maximum after only 9–10 min of exposure to SDM. This data clearly shows the effectiveness of SDM to hydrolyze starch after short-time incubation and the feasibility of using this inexpensive grain source for production of liquefied foods with high solids content. Recently, Griffith et al (1998) concluded that germination of different cereals and legumes was a very effective way to reduce food viscosity and increase nutrient density. Gopaldas et al (1988) observed a 40% viscosity reduction in pastes elaborated from 1% malted wheat and 14% wheat flour, and 61% reduction when a commercial amylolytic enzyme (Takadistase) was used. Almeida et al (1993) achieved 90% viscosity reduction in cereal-based weaning foods liquefied with malted sorghum after only 5 min of incubation at 30°C. Similar results were reported using diastatic malt from sorghum (Mosha and Svanberg 1983) and barley (Hansen et al 1989).

Weaning foods with 15% solids produced from 33.3% SDM and 66.6% RMZ, QPM, or DPM contained ≈610 kcal/L. Therefore, for a 6-month to 1-year-old weaned infant (9 kg, live weight), 4 bottles of 350 mL per day will meet an 850 kcal daily energy requirement (RDA 1989). Higher solid foods can be prepared for older infants with higher energy requirements and capable of consuming more viscous gruels, thus enhancing nutrient density and intake.

Protein Quality of Weaning Foods

As expected, QPM contained the highest amounts of lysine (4.44 g/100 g of protein) and tryptophan (0.88 g/100 g of protein), whereas DPM contained the lowest levels of these two essential amino acids (2.34 and 0.25 g/100 g of protein, respectively). SDM had lower lysine content (2.65 g/100 g of protein) than RMZ (3.1 g/100 g of protein). Amino acid composition of these cereals is within the ranges reported by other authors (Sproule et al 1988, Rooney and Serna Saldivar 1991, Serna Saldivar et al 1991). DPM lost EAA after decortication due to the partial removal of germ tissue rich in albumins and globulins. For both maize sources, the high levels of lysine observed are due to low protein content (Table III). Within a grain source, the higher the protein content the higher the amount of lysine-deficient prolamins (Wall and Paulis 1978). EAA scores, obtained by dividing the essential amino acid present in the lowest amount by the corresponding requirement for a 2-year-old infant, were highest for QPM followed by RMZ and SDM (Table III). DPM had the lowest EAA score and provided only 40 and 22% of the tryptophan and lysine required by a 2-year-old infant (FAO/WHO 1990). For the rest of the cereals tested, lysine was the limiting amino acid. Chung et al (1985) mentioned that the first limiting amino acid for cereal grains is lysine and the second is tryptophan for maize and threonine for sorghum. QPM contained 23 and 19%

more lysine and tryptophan when compared with RMZ and 36 and 57% than DPM. Sproule et al (1988) found EAA scores for QPM and regular maize of 72.4 and 48.2%, respectively, values that are similar to the ones observed in this study. For DPM, Serna Saldivar et al (1994) determined EAA scores of ≈50% for whole pearl millet and 42% for the corresponding decorticated kernels, lysine being the most limiting EAA. The values obtained in this study are smaller probably because of the higher extent of decortication that removed more EAA, as well as the cultivar used. Almeida et al (1994) reported EAA scores for malted sorghum of 52%, a value slightly higher than that found in this study.

In Vivo Rat Assays

Protein digestibilities. In vivo protein digestibilities for the four treatments tested differed statistically ($P < 0.05$). As expected, the control casein group had the highest amount of digested protein (94.5%), which agrees with previous data obtained by Serna Saldivar et al (1988, 1994). Among cereal sources, DPM weaning food had a slightly higher protein digestibility ($P < 0.05$) than the maize treatments (Table IV). Decortication of pearl millet eliminated the fiber-rich pericarp tissue, thus increasing the rate of protein digestibility. Fiber compounds act as a barrier against enzymes in vivo or in vitro, and the protein associated with these chemical compounds are more difficult for monogastric animals to digest (Fleming and Lee 1983, Ikeda and Kusano 1983, Pedersen et al 1983). In a previous study, Serna Saldivar et al (1994) found similar protein digestibility values for DPM. The protein digestibility of RMZ was ≈1% higher than the digestibility observed in the QPM fed group. Eggum (1985) reported a protein digestibility of 87.6% for regular maize, a value very similar to that obtained in this study (Table IV). Sullivan et al (1988) and Serna Saldivar et al (1988) found similar rates of protein digestibilities for QPM and normal maize fed to pigs and laboratory rats, respectively. As expected the PDCEAAS of the QPM-based diet was higher than RMZ- or DPM-based diets. For these experimental diets, the EAA score (Tables III and IV) had the most effect on overall nitrogen retention values and PER.

Nitrogen retention study. As expected, animals fed the control casein diet retained the highest amount of the ingested nitrogen. The BV for the control-casein diet was 96.4%. Interestingly, rats fed the QPM weaning food retained 88.6% of the nitrogen, absorbed or digested. BV were 7 and 16% lower in RMZ and DPM diets when compared with the QPM weaning food (Table IV). The higher lysine content of the QPM-based diet favored nitrogen retention by the growing rat. Serna Saldivar et al (1994) reported smaller BV for sorghum, high lysine sorghum, and pearl millet in diets balanced to contain 10% protein. Sullivan et al (1988) found biological values of 48 and 67% in growing pigs fed regular maize and QPM, respectively. The high BV observed in this study are due to the low level of protein in the diet (Table I) that decreased protein intake. Eggum (1985) mentioned that dietary protein intake had a marked effect on BV. The lower the protein in the diet, the higher the amount or protein retained. NPU values were also high, in contrast with other studies (Serna Saldivar et al 1987, 1988, 1994). Results clearly show that the control casein and QPM-fed rats retained nitrogen more efficiently, followed by RMZ- and DPM-fed rats.

PER. Rats fed the control casein diet used dietary protein more efficiently when compared with counterparts fed the cereal-based weaning foods (Table IV) due to high casein essential amino acid scores, protein digestibility, BV, and NPU. For cereal-based foods, lysine and tryptophan limit nitrogen utilization, retention, and growth. Interestingly, rats fed QPM- and SDM-based diets gained significantly more weight per gram of protein intake than counterparts fed similar diets based on RMZ or DPM. The improved essential amino acid patterns or scores and the higher nitrogen retention values observed in the QPM-based weaning food (Table III) clearly improved rat performance (Table IV). Rats fed the QPM weaning food gained 86% more weight per gram of protein ingested when compared with counterparts fed RMZ. The PER of DPM weaning food was smaller than RMZ because the diet contained lower EAA scores, PDCEAAS, and nitrogen retention values (BV and NPU). Serna Saldivar et al (1994) and Sproule et al (1988) found better weight gains and greater efficiency of food conversion in animals fed high lysine sorghum or QPM when compared with animals fed regular maize, sorghum, or pearl millet. The QPM weaning food had 87% of the PER value found for the casein-based diet indicating that the high lysine corn can be very beneficial for groups of people who depend on corn as the staple food.

PER was positively correlated ($P < 0.01$) with dietary lysine content, EAA scores, BV, and NPU ($r^2 > 0.85$), indicating that this amino acid was the variable that affected the most rat growth and performance (Table V).

TABLE III
Essential Amino Acid Scores of Casein and Different Cereals Used to Produce Liquefied Weaning Foods[a]

Amino Acid	RMZ	QPM	DPM	SDM	Casein[b]
Phe + Tyr	160.2	119.7	140.0	149.8	162.0
His	187.4	224.2	123.7	121.1	132.1
Ile	138.6	112.9	166.1	146.1	168.4
Leu	229.5	136.7	185.2	201.2	139.5
Lys	53.6	76.6	40.3	45.7	127.1
Met + Cys	207.6	210.0	169.6	135.6	114.9
Tre	119.7	123.8	124.1	105.0	113.3
Trp	60.9	80.0	22.7	nd[c]	113.6
Val	150.0	156.3	160.3	142.9	180.0
EAA score[d] (%)	53.6	76.6	22.2	45.7	100.0

[a] Quality protein maize (QPM), regular maize (RMZ), decorticated pearl millet (DPM), and sorghum diastatic malt (SDM). Results are expressed on dry matter basis and are the average of two observations.
[b] Essential amino acid score (EAA) of casein (AIN casein purified high nitrogen) obtained from Serna-Saldívar et al (1988).
[c] Not determined.
[d] EAA requirement for a 2-year-old infant (FAO/WHO 1990).

TABLE IV
Essential Amino Acid (EAA) Scores, Protein Efficiency Ratios (PER), and Nitrogen Retention Values of Weaning Foods Produced from Malted Sorghum and Different Types of Cereals[a]

Variable[b]	RMZ	QPM	DPM	Control	MSD[c]	SE[d]
Protein digestibility	86.3a[e]	88.4b	91.1c	94.5d	1.220	0.421
EAA score	50.9	66.3	30.0	100	···	···
PDCEAAS	44.0	58.6	27.3	94.5	···	···
BV	81.5b	88.6c	72.8a	96.4d	1.799	0.621
NPU	70.4b	78.3c	66.3a	91.2d	2.338	0.807
PER	1.17b	2.19c	0.70a	2.50d	0.291	0.100

[a] Experimental diets contained 66.6% of the cereal + 33.3% sorghum diastatic malt. RMZ = regular maize, QPM = quality protein maize, DPM = decorticated pearl millet.
[b] PDCEAAS = protein digestibility corrected EAA score, BV = biological value, NPU = net protein utilization value, PER = corrected protein efficiency ratio.
[c] Minimum significant difference, $P = 0.05$.
[d] Standard error.
[e] Values followed by the same letter in the same row are not significantly different ($P < 0.05$).

TABLE V
Correlations Among Different Variables Evaluated During Nutritional Assays[a]

	PER	PD	BV	NPU	EAA	Lysine
PER	1.000**[b]	0.385*	0.909**	0.872**	0.917**	0.859**
PD	···	1.000**	0.433*	0.656**	0.365*	0.638**
BV	···	···	1.000**	0.964**	0.982**	0.935**
NPU	···	···	···	1.000**	0.931**	0.973**
EAA score	···	···	···	···	1.000**	0.937**
Lysine	···	···	···	···	···	1.000**

[a] PER = corrected protein efficiency ratio, PD = protein digestibility, BV = biological value, NPU = net protein utilization, EAA = essential amino acid score.
[b] *, ** = $P < 0.05$ and $P < 0.01$.

CONCLUSIONS

This study clearly demonstrates the feasibility of producing liquefied weaning foods using malted sorghum and simple processing techniques. Cereal grains can be decorticated and milled into flours using traditional or commercial procedures and sorghum malt produced by tribal or commercial malting. Gelatinization can be achieved by adding flours to boiling water and starch liquefaction can be achieved by adding sorghum diastatic malt to the gelatinized paste when the temperature drops to 45–50°C. The low viscosity imparted by the sorghum malt allows flexibility for manipulating weaning food consistency, solid concentration, and nutrient density. QPM-based weaning foods had a much better protein quality when compared with regular cereals. Therefore, QPM-based weaning foods can upgrade the nutritional status of many infants who consume cereals daily due to the better protein quality or essential amino acid composition. The dramatic improvement in the nutritional value of QPM-based foods is easily worth the plant breeding efforts currently being made throughout the world.

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[Received January 6, 2000. Accepted May 24, 2000.]