Quality Protein Maize: Digestibility and Utilization by Recovering Malnourished Infants

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ABSTRACT. The opaque-2 gene was shown years ago to increase the nitrogen, lysine, and tryptophan contents of maize and to markedly increase its nutritional value for small children. Concerns about decreased yield, resistance, and acceptability discouraged further development of the gene. Quality protein maize, while retaining the opaque-2 characteristics, has overcome those constraints. Six recovering malnourished infants received diets in which all of the 6.4% protein energy was supplied by casein, quality protein maize, or common maize. The quality protein maize supplied 60% and common maize 75% of total energy. Vegetable oil was added to increase fat contents to 10% of total energy in all diets. Energy digestibility was less (87% and 84%) from quality protein maize and common maize than from casein diets (94%); most of the difference was due to carbohydrate digestibility. Apparent N absorptions from quality protein maize (70 ± 5%) and common maize (69% ± 7%) were much lower ($P < .01$) than from casein (82% ± 4%). Apparent retention of N from quality protein maize (34 ± 4%) was less ($P < .01$) than from casein (41% ± 9%) but greater ($P < .01$) than from common maize (22% ± 10%). Breath hydrogen excretions were usually greater during quality protein maize consumption than during casein diets but not nearly as much as those during common maize diets. The nutritional advantages of quality protein maize *v* common maize are of a magnitude that must be exploited for the advantage of children in maize-consuming poor countries. *Pediatrics* 1989;83:416–421; *maize, malnutrition, nutrition.*

Infants in developed countries and among the more affluent families in underdeveloped countries are successfully weaned to a wide variety of safe and nutritious foods and are usually given supplementary vitamins and minerals to further guarantee the adequacy of their generous diets.

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The millions of infants from very poor families in the underdeveloped world who need supplements to or substitutes for breast milk lead precarious existences. In homes without electricity or running water, cow's milk is unaffordable or dangerously contaminated, and families usually rely for most of their protein and energy needs on a single staple food, usually a cereal, with or without appropriate supplementation, most commonly by a legume. When the staple is wheat, rich in protein but deficient in one amino acid, a relatively small amount of a lysine-rich legume, fish, or cheese can guarantee an adequate supply of balanced protein, and child growth can be satisfactory, as in the wheat-growing areas of India. Even without the supplement, its high protein content, versatility of food forms, and excellent digestibility make it possible to consume enough wheat to support nearly normal growth.[1] When the staple is rice, with a more balanced amino acid composition but a low content and digestibility of protein, slow growth and a small eventual stature are the rule.[2] The availability of high-protein rice varieties[3] or the addition of appropriate protein-rich supplements[4] markedly enhance growth.

Third in importance as a staple human food is maize: it has a moderately low content of protein that has an unfavorable amino acid composition. There is a marked deficiency of lysine and tryptophan, a moderate deficiency of isoleucine, and an excess of leucine, a constellation contributing to the development of pellagra or florid kwashiorkor.[5] The simultaneous consumption of legumes considerably mitigates these risks, but it is a common practice to withhold the legumes from infants and small children.[6] It is impossible to support anything near a normal and healthy growth with ordinary maize as the only source of amino acids.

The 1964 report by Mertz and associates[7] on the opaque-2 gene, which resulted in the introduction of high-lysine, high-tryptophan characteristics into common or hybrid maize, was hailed as a potential godsend for millions of maize consumers. The benefits to infants and small children were conclusively documented,[8,9] but it was also recognized that these improvements were associated with lower yields, soft endosperms, and lowered resistance to parasites and disease.[10] Soon thereafter, a rash of publications that downplayed the importance of protein in setting nutrition policies[11] led to a serious curtailment of further research into the perceived weaknesses of this genetic breakthrough. A large field study in Guatemala, well on the way to demonstrating the nutritional gains from the introduction of opaque-2 maize varieties into an entire valley, had its funding abruptly terminated.[12] The International Maize and Wheat Improvement Center, with funding from the United Nations Development Program, continued to pursue this research and eventually to develop varieties of quality protein maize that, together with undiminished yields, have hard endosperms and disease resistance that were introduced through further gene modifiers.[13] Many varieties have higher protein contents than their parent strains. In the present report, the digestibility and use of the protein and energy in a common parent strain of maize, ICTA B-1 from Guatemala, and of a derived variety into which the quality protein maize characteristics have been successfully introduced and maintained (NUTRICTA) are simultaneously evaluated in recovering malnourished infants.

TABLE 1. Proximate Composition and Critical Amino Acid Content of Common (ICTA B-1) and Quality Protein Maize (NUTRICTA) From Guatemala

Composition and Amino Acid Content	Common Maize (ICTA B-1)	Quality Protein Maize (NUTRICTA)
% protein (N × 6.25)	8.20	10.15
Moisture (g/100 g)	7.19	7.31
Fat (g/100 g)	4.45	5.05
Ash (g/100 g)	1.04	1.34
Crude fiber (g/100 g)	2.20	2.15
Energy (kcal/100 g)*	409.2	417.6
Amino acids (% of protein)†		
Lysine	2.60	3.92
Tryptophan	0.60	0.88

* Bomb calorimetry.
† Analyses by Dr Eva Villegas, International Maize and Wheat Improvement Center.

TABLE 2. Composition of Casein Control Diet and of Two Quality Protein and Common Maize Diets*

Ingredients	Casein Control	Quality Protein Maize	Common Maize
Maize		15.76	19.51
Casein†	1.86		
Vegetable oil	1.22	0.35	0.27
Sucrose	6.97	4.64	2.96
Corn syrup solids	7.18	4.76	3.03
Corn starch	8.14		

* All values are given in grams, except vegetable oil (equal parts of soya and cottonseed oils), which is given in milliliters per 100 kilocalories. Vitamin and mineral mixes are added to satisfy National Research Council, recommended intakes, Na to make 2.4 mEq, K 3.0 mEq/kg/d.
† Casec (Mead Johnson, Evansville, IN).

MATERIALS AND METHODS

In Table 1, the proximate composition of the two varieties of maize as well as the contents of two essential amino acids that almost equally limit the use of standard maize protein are listed. Both varieties were wet-milled into whole kernel meals. In Table 2, the composition of the two maize diets and of a casein control diet are listed. These diets supplied 6.4% of energy as protein, 10% as fat, and the balance as carbohydrate. This level of protein is one that we have found to be consistently adequate for infants more than 3 months of age consuming casein as the only source of protein. The nutritional value of other protein sources relative to casein can be ascertained by feeding them to infants at the same level.

Quality protein maize had to supply only 60% of total energy to provide 6.4% of energy as protein in the diet; common maize, because of its lower protein content, had to supply almost 75% of total energy. The addition of small amounts of vegetable oil brought total fat in the diets to 10% of energy, with 71% and 78% of this coming from quality protein maize and common maize, respectively. Isoenergetic amounts of sucrose and corn syrup solids were added to complete 83.6% carbohydrate energy, of which 58% and 73% came from quality protein maize and common maize, respectively. An isonitrogenous casein control diet with the same macronutrient distribution was made by adding vegetable oil and an isoenergetic mixture of sucrose, corn syrup solids, and corn starch (Table 2). Vitamin and mineral mixes were added to all diets to satisfy intakes recommended by the Food and Nutrition Board, National Research Council, for children of the corresponding age.[9]

Six recovering malnourished infant boys participated in these studies with the informed, written consent of their parents. They were 7.9 to 18.5 months of age (Table 3) when they entered the studies but their height ages, with reference to the National Center for Health Statistics data[14] were

TABLE 3. Nutritional Status of Six Recovering Malnourished Infant Boys Given Diets of Common Maize, Quality Protein Maize, and Casein

Infant No.	Wt Age (mo)	Wt (kg)	Wt Age (mo)	Height (cm)	Height Age (mo)	%	Wt for Height*		Serum Albumin (initial g/dL)
							Percentile	Z Score	
936	10.3	6.00	3.0	61.4	3.1	99	50–60	0.12	3.49
938	10.6	7.20	4.8	67.1	5.6	95	20–30	−0.71	3.64
952	18.5	7.66	5.5	73.2	9.5	82	3	−2.14	4.17
949	7.9	6.05	3.0	66.0	5.0	83	3	−1.90	4.35
961	9.0	5.24	2.0	63.0	3.7	81	3–5	−1.90	3.77
968	10.0	4.27	1.0	56.5	1.5	90	20–30	−0.62	4.21

* According to National Center for Health Statistics measurements.

only 1.5 to 9.5 months, indicative of long-standing undernutrition. Their weight ages were 1.0 to 5.5 months. Three of the six had reached or exceeded 90% of the weight expected for their height, were between the 20th and the 60th percentiles of weight for height (National Center for Health Statistics), and had Z scores (number of standard deviations greater than or less than the National Center for Health Statistics median) of −0.71 to +0.12 for this value. The other three infants had attained only 81% to 83% of the weight expected for their height, were between the third and fifth percentiles, and had Z scores of −1.90 to 2.14 for the same measures. All six had serum albumin levels of 3.49 g/dL or more, were free of any apparent infection, were gaining weight steadily, and had demonstrated no evidence of malabsorption from a cow's milk-based formula.

The protocols for these studies were approved by the Ethics Committee of the Instituto de Investigacion Nutricional, Lima, Peru.

Energy intakes during these studies were approximately 125 kcal/kg/d, calculated to support weight gain and growth at previously established rates. All subjects received the casein control diet during the first nine days, followed by the two maize diets for seven days each. Three children received the quality protein maize first, three the common maize. Quantitative collections of urine and feces were carried out during the last four days of each diet period, making use of a metabolic bed or a stroller adapted for the same purpose. Determinations of total nitrogen in diet, urine, and feces (micro-Kjeldahl method), of energy content in diet and feces (adiabatic bomb calorimetry), of fat content in feces,[14a] and of carbohydrate content (calculated by difference) in feces were made in two two-day collections. Breath hydrogen (Quintron model 12 Microlyzer chromatograph) concentrations were estimated before the first feeding of the day and hourly thereafter for seven hours on the last two days of each diet period. The second feeding was given four hours after the first. Subsequent experience with other cereal diets has suggested that fewer determinations in the first four hours and a prolongation beyond seven hours might have been more informative.

Results of the balance studies with the casein and each of the maize diets were compared with each other by paired t tests.

RESULTS

All of the children consumed the three diets readily, with no signs of intolerance. The results of the balance studies are summarized in Table 4, as are the changes in body weight and in serum albumin levels. These last two measurements are of relatively minor importance, the first because weight changes during such short periods can be affected by the intestinal contents and by changes in hydration, the second because longer periods are usually needed for diets marginally deficient in protein to affect serum proteins.

Fecal wet weights were only slightly greater during the quality protein maize diets than during the casein diets. The significantly greater weight during the common maize period is due in part to the greater maize consumption required by its lesser protein content. Fecal dry weight and energy were at least twice as great during the quality protein maize diets, only partly the result of their fiber contents, and were still greater during common maize diets, again related to the greater contribution to the diet by the maize. Fat absorption was very satisfactory, as with most high-fiber diets in our experience.[3,9,15] The high excess calculated carbohydrate excretions are greater than can be explained by the fiber contents of the maize and must represent a mixture of bacterial polysaccharides, indigestible fiber, and malabsorbed starch and oligosaccharides.

The high fecal nitrogen during both maize diets may represent bacterial nitrogen plus some unabsorbed protein.[16] Of greatest importance are the lower nitrogen retentions from quality protein maize than from casein, some of which can be

TABLE 4. Digestibility and Use by Six Infants of Energy and Protein From Common Maize, Quality Protein Maize, or Casein Diets*

Measurements	Casein	Quality Protein Maize	Common Maize
Fecal			
Wet wt (g/d)	80 ± 33[a]	108 ± 28[a]	129 ± 19[b]
Dry wt (g/d)	14 ± 4[a]	29 ± 7[b]	34 ± 5[c]
Energy			
kcal/d	48 ± 11[a]	121 ± 27[b]	137 ± 17[c]
% of intake	6 ± 1[a]	13 ± 2[b]	16 ± 1[c]
Fat			
g/d	1.3 ± 0.4	0.9 ± 0.3	1.3 ± 0.3
% of intake	14 ± 4	9 ± 4	13 ± 4
Carbohydrate			
g/d	5 ± 2[a]	22 ± 7[b]	24 ± 4[b]
% of intake	3 ± 1[a]	11 ± 3[b]	13 ± 1[b]
Nitrogen			
Intake (mg/d)	2,181 ± 292	2,273 ± 295	2,256 ± 299
Absorption (% of intake)	82 ± 4[a]	70 ± 5[b]	69 ± 7[b]
Retention (% of intake)	41 ± 9[a]	32 ± 4[b]	22 ± 10[c]
Body wt gains			
g/d	33 ± 6	25 ± 16	18 ± 16
g/kg/d	5.4 ± 1.0	3.9 ± 2.7	2.6 ± 2.3
Serum albumin (g/dL)			
Change	0.0 ± 0.4	0.0 ± 0.4	−0.3 ± 0.3
Final	3.8 ± 0.3	3.7 ± 0.5	3.6 ± 0.4

* Values along same line with different letter superscripts are significantly different from each other ($P < .05$). Values are given as means ± SD.

explained by slightly inferior amino acid composition, some by the effects of less retained energy, and much more by the inferior apparent N absorption. As percentages of absorbed N, the so-called biologic value, the retentions from both sources were nearly identical. The much lesser retentions from common maize, 50% to 55% of the casein values and 65% to 70% of the quality protein maize values, are undoubtedly due to the same factors, but with inferior amino acid composition assuming a more important role. Weight gains, although paralleling the nitrogen retentions on the average, were not significantly different; neither were changes in serum albumin significantly different.

In the Figure the breath hydrogen concentrations of the six infants while consuming the casein control and the two maize diets is seen. Almost without exception, the seven-hour studies were carried out twice with each diet on the fifth and sixth days of consumption. Only on three occasions during the casein diets, fasting and during the first two hours after the first meal for infant number 936, was the hydrogen concentration as great or greater than 20 ppm. If these increases had been due to small bowel malabsorption of the starch or oligosaccharides of the casein diet, it is likely that they would not have been seen in the fasting state or first hour and that they would have begun in the second hour after each of the two meals consumed during the study. Their timing, as well as that of the minor increases seen in the other subjects during the fourth to seventh hours and in the fasting state, suggest another substrate for the hydrogen production: mucosal polysaccharides or fiber remaining from previous diets.

In only one of the infants consuming quality protein maize (infant No. 961) were there no increases in the breath hydrogen greater than 20 ppm; in one of the other infants (infant No. 968), during one of the studies, there was the delayed increase characteristic of most cereal-based diets and, presumably, due to fermentable fiber.[17] In the remaining four subjects, fasting concentrations were at or greater than 20 ppm, particularly in infants' No. 952 and 949, tended to decrease gradually during the next four hours, and then started a trend of increase that, unfortunately, was not fully documented. The increased fasting values and the reports of others[17] suggest that breath hydrogen concentrations may have continued to increase during the day as the result of the cumulative effect of the five meals, probably reached their peak in the early morning hours, and were falling by the time the fasting samples were obtained. The smallest increases of breath hydrogen were seen in the infants with the least body weights and, consequently, the smallest consumptions of quality protein maize. Furthermore, the greatest increases were seen in the infant with the greatest weight and the greatest consumption.

In only one infant (number 938) were the breath hydrogen concentrations during the consumption

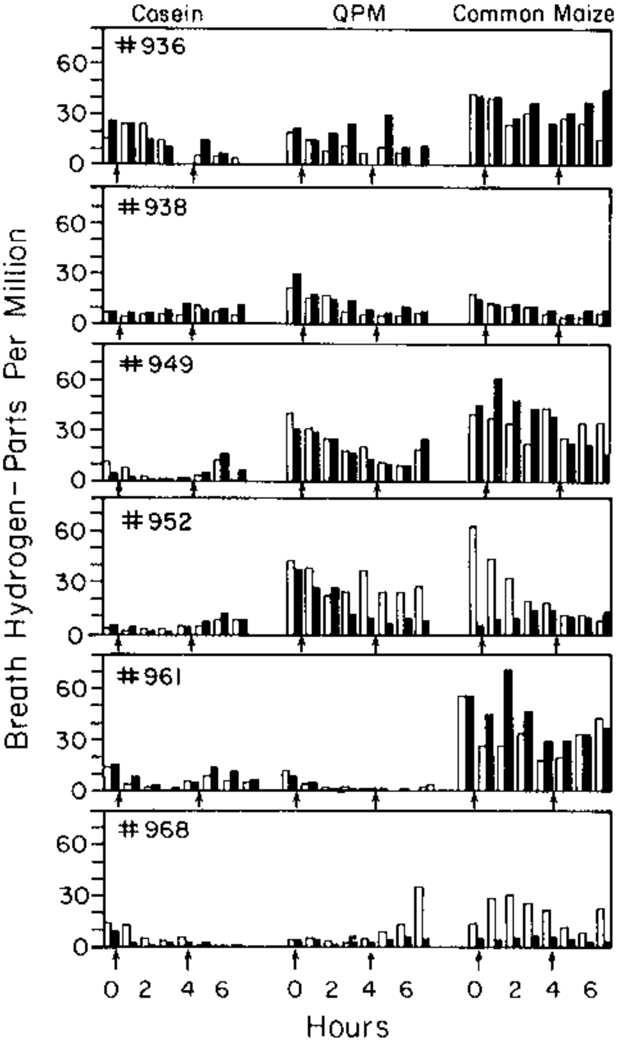

Figure. Breath hydrogen concentrations of six infants on fifth and sixth days of consuming casein, quality protein maize (QPM), and common maize diets: pairs of values correspond to fasting state (eight hour) and to seven-hourly values after first meal of day. Arrows indicate time of each meal.

of common maize as small or less than those during quality protein maize consumption. In one other infant (No. 968) the absolute peak was less, but most of the values were greater than those during quality protein maize diets. In the remaining four, most notably in infant No. 961, the concentrations were greater and infant weight did not seem predictive. The fact that concentrations were generally greater might be due to the greater consumption of carbohydrates from common maize required to equal the protein consumption from the casein and quality protein maize diets or due to intrinsic differences in digestibility of the two maize varieties.

DISCUSSION

It has been known for more than 20 years that incorporation of the opaque-2 gene into maize results in an increased protein concentration and in a notable increase in the concentration of lysine and tryptophan.[7] It is also generally acknowledged that these changes translate into a much improved nutritional value for infants and children.[8,9] The fact that decreased yields, resistance, and acceptability are no longer obligatory accompaniments of these nutritional improvements is generally ignored.[13] The present study documents the fact that high-yielding, high-protein, high-lysine, high-tryptophan, hard endosperm, disease- and parasite-resistant varieties of maize, when consumed as the only source of protein and as 60% of the energy in the diet of infants and small children, support apparent retentions of nitrogen that are 45% greater than those from standard maize and 78% of those from casein. Metabolizable energy intakes from such quality protein maize diets are moderately but significantly greater (87% *v* 84%) than those from the common maize diets but still less than those from the fiber-free casein diets (94% of gross energy intake). Apparent absorption of nitrogen from the casein diets was considerably greater than that from the maize diets (82% *v* 70% and 69%). From the current studies, it is impossible to tell how much of the increased fecal energy and nitrogen is from undigested and unabsorbed components of maize and how much from proliferation of microorganisms using the carbohydrate reaching the colon as a source of energy for multiplication.

In those children with minor or no increases of breath hydrogen while consuming maize, fecal losses of energy and nitrogen were as great as in those with much greater hydrogen excretions, suggesting that microbial proliferation does not always lead to fermentation. The lesser production of hydrogen during quality protein maize consumption than during common maize consumption may have nutritional implications other than the probable advantage of having less abdominal distention and flatus.

To anyone familiar with the nutritional problems of weaned infants and small children in the developing countries of the world, and with the fact that millions of them depend on maize for most of their dietary energy, nitrogen, and essential amino acids, the potential advantages of quality protein maize are enormous. To assume that these children will always be given a complementary source of nitrogen and amino acids is a cruel delusion. We have more recently demonstrated that quality protein maize, as the only source of protein (±9% of total energy) and fat (±10% of total energy) in the diet of weaned infants and small children, can support growth equivalent to that attained with sophisticated cow's milk-derived formulas. This would not only be impossible with common maize, it would be unethical to attempt.

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