Nutritional Effectiveness of Soy Cereal Foods in Undernourished Infants

GEORGE G. GRAHAM and **JUAN M. BAERTL**, Department of International Health, School of Hygiene and Public Health, Baltimore, Maryland

ABSTRACT

These studies show that a variety of cereal-soy foods can be the major or only source of protein in the diet of growing infants and children. These included various combinations of cornmeal and soy flour, with and without added dry skim milk or methionine; a wheat flour-wheat concentrate mixture or whole wheat flour with soy flour; oat and soy flours; and a corn-wheat-soy flour macaroni. Apparent absorption of nitrogen from each of these mixtures was similar, averaging 76.3 ± 0.6 (SEM) % of intake, but was inferior to that from casein in the same children, which averaged 86.8 ± 0.4% of intake. Apparent retentions of nitrogen averaged 26.6 ± 0.8 and 33.8 ± 1.0% of intake respectively, with all but one of the soy-cereal combinations being similar. This one had a mean retention equal to that from casein, possibly as the result of "instantizing" of the cornmeal which probably resulted in increased availability of dietary energy. For all the mixtures, nitrogen retention was influenced by the efficiency of nitrogen absorption, suggesting that processing methods can improve the nutritional quality of these foods.

INTRODUCTION

During the last 10 years we have acquired experience in the evaluation of various soy-cereal combinations in the diets of normal, convalescent malnourished, or malnourished infants and small children. Some of these products were compared to each other in the diet of the same children and all were compared to casein as the only source of protein in the diet of each child. The nutritional value of the protein mixture in these foods, as measured in children, generally tended to confirm the protein efficiency ratio (PER) as measured in the rat, but there were some significant discrepancies. There were enough differences between these products, and between them and casein, to make a study of these differences important. We have had some experience with a product not included in this report, a variant of Incaparina in which soy flour replaced half of the cottonseed flour, but our studies were of a limited and somewhat different nature.

MATERIALS AND METHODS

The corn-soy-milk mix (CSM) we evaluated was an early version without added soy oil and was made available to us by the Agency for International Development, as was a wheat-soy blend (WSB). The Mx-86, also spoken of as "instant CSM" and as "post-kwashiorkor feeding mixture" (PKFM), was made available to us by UNICEF. This mixture had been subjected to special extrusion cooking which eliminated the gelatinization property of the cornmeal, thus decreasing its water holding properties and its bulkiness in the gastrointestinal tract. Fortifex was made in Brazil by Nestle and was made available by UNICEF, as were Mx-44 and Mx-45, wheat-soy and oat-soy blends made by Quaker of Colombia. GF-1 and GF-2 represent a corn-soy-wheat macaroni, without and with added methionine, which was developed by the General Foods Corporation.

Table I lists the ingredients of these various foods. All but one, Mx-86, used defatted soy flour. The Mx-86 contained 38% full-fat soy flour. The first three products had cornmeal as the only cereal, the next two a mixture of corn and wheat flours, the next one a mixture of wheat flour and wheat concentrate in almost equal parts, the next whole wheat flour, and the last whole groat oat flour. Mx-86, along with the same amount of dry skim milk as in CSM, contained 15% sugar and was studied with and without 0.3% added DL-methionine. The addition of this amino acid did not significantly affect the results and consequently all the results with this product have been pooled. These foods contained between 19 and 28.8% protein and between 0.1 and 8.5% fat. All contained appropriate amounts of added vitamins and minerals but we did not attempt to measure their availability. The lowest PER in rats was 2.05 and the highest was 2.45, adjusted to

TABLE I

Ingredients, Composition, and PER[a] of Soy-Cereal Foods

Food	Ingredients			Composition		PER
	Soy flour[b]	% Cereal	Other	Protein	Fat	(Casein 2.50)
CSM	25.0% TD	68.0% Gelat. cornmeal	5.0% DSM	19.0%	2.0%	2.45
Mx-86	38.0% FF	39.9% Cornmeal	5.0% DSM 15.0% Sugar	20.5%	8.5%	2.30
Fortifex	50.0% D	49.0% Cornmeal	0.2% DL-met	—	—	—
GF-1	27.8% D	49.8% Corn flour 19.4% Wheat flour	—	20.7%	0.1%	2.33
GF-2	27.8% D	49.8% Corn flour 19.4% Wheat flour	0.27% DL-met	20.7%	0.1%	2.41
WSB	16.4% TD	40.7% Wheat flour 40.5% Wheat concentrate	—	24.0%	3.9%	2.05
Mx-44	35.0% D	62.9% Whole wheat flour	—	27.0%	1.8%	2.20
Mx-45	35.0% D	62.9% Whole groat oat flour	—	28.8%	4.8%	2.32

[a]PER = protein efficiency ratio.

[b]Soy flours: TD = toasted defatted, D = defatted, FF = full fat.

TABLE II

Apparent Nitrogen Absorptions and Retentions from Soy Cereal Foods in 26 Children[a]

Food	No. of subjects	No. of 3 day studies	Absorption (% of intake)		Retention (% of intake)		Retention vs. absorption correlation		
			Mean	SEM	Mean	SEM	"r"	"P"	Slope
CSM	10	41	73.0	1.3	27.4	1.6	0.63	<0.01	0.80
Mx-86	3	12	78.1	0.9	33.8	1.9	0.70	<0.01	1.53
Fortifex	4	9	74.6	1.4	26.5	2.0	0.21	n.s.	0.31
GF-1	6	12	77.6	1.0	24.9	2.5	0.39	n.s.	1.01
GF-2	5	14	79.6	1.7	26.7	3.9	0.65	<0.05	1.27
WSB	5	22	75.7	1.1	23.4	2.3	0.42	<0.05	0.90
Mx-44	3	15	78.7	1.1	25.4	1.6	0.74	<0.01	1.08
Mx-45	3	12	80.6	1.8	25.9	2.0	0.41	n.s.	0.47
8 Foods	26	137	76.3	0.6	26.6	0.8	0.48	<0.01	0.71
Casein	25[b]	138	86.8	0.4	33.8	1.0	0.04	n.s.	0.08

[a]Correlation coefficients "r" between absorption and retention for each food, for all combined, and for the control casein diets. Also listed are the "P" values for each "r" and the slope of the regression equations.

[b]One subject did not have a control casein period.

casein at 2.50. At the time of this writing we did not have available the PER for the batch of Fortifex which we used but our recollection is that it was in the same range, probably ca. 2.3.

In all of these studies enough cottonseed oil, and a mixture of sugar and cornstarch, were added in order to lower the protein content of the final mixture into a range critical enough to measure differences in utilization of protein. For all the comparative studies protein provided between 6.4 and 8.0% of calories in the diet. Of the non-protein calories in the prepared diets ca. half came from fat and half from carbohydrate. Vitamin and mineral mixtures were added when necessary to the final diet in amounts sufficient to satisfy the minimum daily requirements of all the children. After appropriate cooking and blending of the final mixtures, enough water was added to permit their administration through a feeding bottle, and to satisfy the water requirement. Diets were recalculated daily to yield the same intake of protein and calories/unit of body wt during the entire study. The nitrogen content of the diet, of the stool, and of the urine was determined by the micro-Kjeldahl technique. As cutaneous and other losses were not measured and endogenous nitrogen excretion was not determined, the absorptions and retentions of nitrogen are considered as "apparent." Because all studies were conducted in an air-conditioned environment, we assume that skin losses were ca. constant during any particular study.

All metabolic collections for the determination of apparent absorption and retention of nitrogen were made in boys because of the much greater ease of complete and separate collections of urine and stool. A minimum of 2, but usually 3 day collections, were made for each diet in each subject after an adjustment period of at least 3 days. All the subjects in these studies were either normal or, if they had been malnourished, had recovered enough to have reached at least 90% of the body wt appropriate to their height. They had normal serum proteins, hemoglobins of at least 10.5 g/100 ml of blood, and no evidence of infection or other disease. Their ages were 6-38 months with the mean near 15 months.

Most of the subjects in the prolonged feeding studies were girls, either normal or similarly advanced in convalescence. They were slightly younger, 6-36 months old with the mean near 9 months. The calorie content of their diet was periodically adjusted to maintain a rate of steady wt gain, ca. 3-6 g/kg of body wt daily. Protein content was simultaneously adjusted to maintain the same percentage of calories as protein, determined on the basis of the child's age and of the results obtained in the comparative studies. With milk protein, ca. 6.4% protein calories are adequate for most infants. In the very young or in the malnourished the requirement can be higher, and in those over 1 year old it decreases gradually. On the basis of the comparisons with casein a protein level was generally chosen which compensated, with a safety margin, for the difference in protein quality.

Prolonged feeding was considered successful if, during a minimum of 3 months, wt gain was maintained, linear growth was normal for biologic age, serum proteins remained in the normal range, and there were no indications of intolerance.

Six of the products were used as the only source of protein in the initial dietary management of infants admitted with marasmus, and young children, under 3 years old, admitted with marasmic kwashiorkor. Treatment in marasmus was considered successful if the food was well tolerated, steady wt gain was established, and serum albumin levels remained in or reached the normal range. It was considered only a partial success if the first two criteria were met but serum albumin remained below the normal range but still above 3 g/100 ml. It was considered a failure if the food was not well tolerated, wt gain was unsatisfactory, or serum albumin fell below 3 gm/100 ml. This last was the most common cause of failure. In kwashiorkor, treatment was considered successful if the food was well tolerated, if loss of edema occurred within the first 10 days of treatment as is common on milk protein diets, if serum albumin rose to above 3.5 g/100 ml within 30 days, and steady wt gain was established after the completion of diuresis. In the treatment of marasmus, the level of protein calories was generally ca. 10% initially and was later reduced to 8%. Calorie intake was increased as rapidly as tolerated to exceed the minimum of 125 Kcal/kg of body wt daily which is usually necessary. In kwashiorkor, calorie and protein requirements are lower and it was seldom necessary to exceed 100 Kcal/kg of body wt daily and 8% protein calories.

RESULTS

Table II summarizes the results of the comparative balance studies for the 8 foods and the control casein diets. One of the subjects receiving Fortifex received a modified milk instead of casein during the control period. It is apparent that more than one food was tested in some of the subjects.

The apparent absorption of nitrogen from casein was consistently quite high and varied within a relatively narrow range. The variation in apparent retention was somewhat wider. There was no correlation between absorption and retention, suggesting that the latter was determined only by the physiologic state of the individual and by calorie intake (1).

The apparent absorption of nitrogen from each of the 8

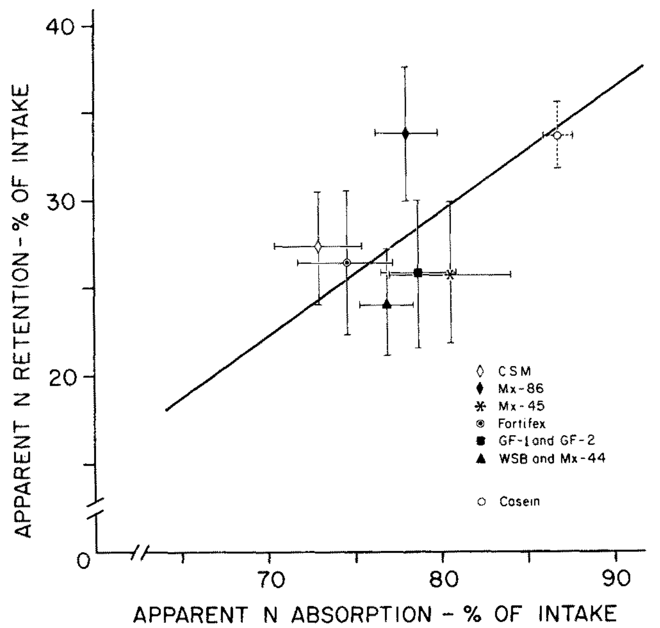

FIG. 1. Regression of apparent nitrogen retention on apparent nitrogen absorption from 8 soy-cereal foods. Bars represent 2 SEM's above and below the means. Results from casein are not included in the calculated regression equation line.

foods was consistently lower than that from casein and had a wider range of variation, even when the results were combined. The differences between individual foods were not large, although those between CSM and both Mx-86 and Mx-45 were significant. Apparent retentions of nitrogen had an even wider range of variation but were not significantly different from each other, with the sole exception of Mx-86, which had a mean apparent retention equal to that from casein and significantly higher than that from most of the other products.

Most important are the highly significant correlations between retention and absorption from the 8 foods combined, and most of them individually. When results from GF-1 and GF-2 are combined, the correlation coefficient increases, as does its significance. The lack of significance of the correlations for Fortifex, GF-1, and Mx-45 is primarily the result of the small number of studies with each product. Included in the table are the slopes of the linear regression equations for retention on absorption from each of the products, and from all combined, without including casein.

The line in Figure 1 corresponds to the linear regression equation for apparent retention on apparent absorption of nitrogen from the 8 soy-cereal foods combined. The means (±2 SEM) for CSM, Mx-86, Fortifex and Mx-45 have been plotted individually, but the results for GF-1 and GF-2, and for WSB and Mx-44, have been combined to avoid crowding, and because their composition and the results obtained were similar. The means (±2 SEM) for casein have also been plotted, although the individual results were not included in the calculation of the line. This point probably represents a break in the line, beyond which further increases in absorption would not be expected to produce additional increments in retention.

For the three cornmeal-based products the mean apparent retentions were above the line calculated for the entire group, while for the corn-wheat combination, wheat, and oat-based products the means fell below the line, suggesting nutritional values above and below those which might have been predicted on the basis of absorption alone.

Table III summarizes the results of additional critical testing of the soy-cereal foods. Seven of them were used successfully as the only source of protein in the diet of convalescent malnourished infants and children for periods of at least 3 months. Because of a limited supply, Mx-86 could not be tested in this fashion. In all cases satisfactory rates of wt gain were maintained, as were normal serum albumin levels. Gains in body length were appropriate to biologic age: the increases in "length age" correspond to the time expired, a reliable indicator of gains in lean body mass (2). In all cases the food in question represented less than 50% of total calories, the difference having been made up with cottonseed oil and sugar.

Only 3 of the products were used as the source of protein in the initial dietary management of cases of infantile marasmus, the most severe test of protein quality that we employ. Both CSM and WSB were well tolerated and supported satisfactory rates of wt gain but did not maintain normal serum albumin levels. In 4 of 5 studies this fell to below 3.0 g/100 ml. Of the 2 infants receiving Mx-86 in the same situation, one maintained normal levels, but in the other serum albumin, although above 3.0 gm, did not reach 3.5 g/100 ml after 1 month.

Four of the products were used in the initial dietary management of cases of kwashiorkor, all successfully. These children are almost invariably older and seem to digest and utilize these vegetable proteins efficiently despite their protein malnutrition.

DISCUSSION

From these studies it is apparent that the various soy-cereal foods tested are all good sources of protein, and at appropriate levels can support normal growth in healthy infants and children and "catch-up" growth in convalescent malnourished infants and children. The failures of 2 of the products in the initial management of cases of infantile marasmus are not surprising. These infants, aside from being younger, usually below 9 months old, have significant physiologic limitations, behaving in many ways, including in their body composition, like premature infants. Although we do not have precise information on the subject, we suspect that the most significant limitation is in their digestive and absorptive capacity, not only for the protein in their diets but also for the other ingredients, particularly complex carbohydrates. The fact that one product, more sophisticated in its processing, could be used successfully, proves that there is no inherent inferiority in an appropriate mixture of vegetable proteins. We have used an isolated soy protein "milk" in an analogous situation with success equal to that of modified cow's milk formulas (3).

The comparative studies bring out the great importance of digestibility in determining utilization. Whereas most of these products had PER's in rats quite close to that of casein, their utilization in human infants and children, with a single exception, was lower than would have been predicted on this basis. The relative rank within the products, with the same exception, was similar to that of the rat studies. This suggests that amino acid composition is an important determinant of utilization and that in general the corn-soy combination was superior to wheat-soy, corn-wheat-soy, or oat-soy combinations. That amino acid composition is not the only determinant is demonstrated by the clear-cut effect of protein digestibility by the human infant. When this was low, apparent retention was affected adversely.

The results with Mx-86 may at first glance seem aberrant. The apparent absorption of nitrogen from this product affected utilization as demonstrated by the highly significant correlation coefficient. It was significantly inferior to that from casein and only slightly better than the average of the soy-cereal foods. Nevertheless the apparent retentions were equal to those from casein, suggesting a higher biological value of the protein, something which seems highly unlikely. A more likely explanation would be a greater "effective" calorie intake for the same protein intake. Since we feel confident that there were no major

TABLE III

Additional Critical Testing of Soy-Cereal Foods as Sole Source of Protein in the Diet of Malnourished Infants and Children

Food	Successful prolonged feeding		Initial diet therapy[a]	
	Ages-months	% Protein Kcal	Marasmus	Kwashiorkor
CSM	8-26	6.4-8.0	0,0,±	
Mx-86	—	—	+,±	+,+
Fortifex	6-12	5.6-6.7		+,+,+,+
GF-1	28	8.0		+,+
GF-2	24-36	10.0		+,+,+
WSB	13-34	8.0-9.6	0,0	
Mx-44	9	8.0-10.0		
Mx-45	18	8.0		

[a]0 = failure, ± = partial success, + = success.

errors in the diet calculations, this could only be due to better digestibility and absorption of the non-protein constituents of the diet. This is supported by the very low stool wts, similar to those from the casein diets, and considerably lower than those from most of the cereal-based diets we have studied. Although not included in this study, the stool wts have been included in a publication of our results with Mx-86 (4).

The results with the wheat-based products also bring out the importance of digestibility. When we have used white flour enriched with lysine (5) or fish protein concentrate (6), we have found absorptions of nitrogen equal to those from casein and, as a probable result, apparent retentions which were considerably higher than those which could have been predicted on the basis of rat PER's or those found here for wheat-soy combinations. The WSB contained equal parts of white flour and wheat concentrate. This last has a superior amino acid composition but is obviously less easily digested by infants and children. The same is probably true for the whole wheat flour used in Mx-44. Lest we become overly enthusiastic over highly refined cereals, we must keep in mind the important recent evidence on the importance of fiber in the prevention of many of the major diseases of the developed world.

In most of these products, the significant methionine deficiency of soy protein was almost completely corrected by the cereal component, making supplementation unnecessary. When soy is to provide most of the protein in a diet, it is essential to add appropriate amounts of methionine as deficiency of this amino acid is a problem of major consequence.

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REFERENCES

1. Graham, G.G., A. Cordano, and J.M. Baertl, J. Nutr. 84:71 (1964).
2. Graham, G.G., A. Cordano, R.M. Blizzard, and D.B. Cheek, Ped. Res. 3:579 (1969).
3. Graham, G.G., R.P. Placko, E. Morales, G. Acevedo, and A. Cordano, Amer. J. Dis. Child. 120:419 (1970).
4. Graham, G.G., J.M. Baertl, R.P. Placko, and E. Morales, Amer. J. Clin. Nutr. 26:491 (1973).
5. Graham, G.G., R.P. Placko, G. Acevedo, E. Morales, and A. Cordano, Ibid. 22:1459 (1969).
6. Graham, G.G., J.M. Baertl, and A. Cordano, Amer. J. Dis. Child. 110:248 (1965).