Donated fortified cereal blends improve the nutrient density of traditional complementary foods in Haiti, but iron and zinc gaps remain for infants

Marie T. Ruel, Purnima Menon, Cornelia Loechl, and Gretel Pelto

Abstract

This research assesses whether fortified cereal blends such as corn-soy blend (CSB) or wheat-soy (WSB) blend can significantly contribute to improving the quality of the diet of infants and young children 6 to 23 months of age. A series of participatory recipe trials was conducted to assess current complementary feeding practices in the Central Plateau of Haiti and to develop new, improved recipes by using a combination of locally available ingredients and foods and donated fortified cereal blends. Our findings show that it is feasible to improve the nutritional quality of complementary foods in poor rural areas of Haiti, using locally available ingredients and fortified cereal blends. Significant improvements in the concentrations of vitamin A could be obtained by including acceptable and affordable amounts of locally available vitamin A-rich foods such as pumpkin or eggs. Only preparations using CSB, however, could achieve the recommended concentrations of iron and zinc in complementary foods, and even this was achievable only for 12- to 23-month-old children. For infants, and especially those between 6 and 8 months of age, the high requirements of 7.7 mg of iron and 1.6 mg of zinc per 100 kcal of complementary foods could not be met, even with a combination of fortified CSB and other locally available, acceptable, and affordable foods. The same was true for the zinc density of complementary foods among 9- to 11-month-old children, which could not be achieved even with fortified CSB. Thus, in this population, fortified cereal blends were key to achieving the recommended iron and zinc densities of complementary foods for children 12 to 23 months of age, but they were not sufficient for infants. Complementary approaches, such as improving the availability, access, and intake of animal-source foods or the use of home fortification techniques (using spreads, sprinkles, or dispersible tablets), are needed to ensure adequate iron and zinc density of complementary foods for infants younger than 12 months in resource-constrained environments such as rural Haiti.

Key words: complementary foods, corn-soy blend, food aid, Haiti, iron, micronutrient deficiencies, recipe trials, vitamin A, zinc

Introduction

Infants and young children in their first two years of life have particularly high energy and nutrient requirements, while at the same time having limited gastric capacity and motor skills. Thus, they require special foods of adequate nutrient density, consistency, and texture, and they need to be fed more often than adults. In resource-constrained populations, diets consist mainly of cereal-based staple foods, and access to nutrient-rich foods such as animal products, fruits, and vegetables is limited. Young children living in these conditions are at particularly high risk of micronutrient deficiencies, including those of iron, zinc, and vitamin A.

Current child-feeding recommendations state that children 6 to 23 months of age should be fed animal-source foods daily, especially if they do not have access to fortified foods or vitamin and mineral supplements [1]. Unfortunately, the families that cannot afford to feed their children animal-source foods on a regular basis are also the ones that have limited access to fortified foods or vitamin and mineral supplements.

A number of Maternal and Child Health programs targeted to poor families in the developing world

Marie T. Ruel and Cornelia Loechl are affiliated with the International Food Policy Research Institute (IFPRI) in Washington, DC. Purnima Menon and Gretel Pelto are affiliated with the Division of Nutritional Sciences, Cornell University, Ithaca, New York, USA.

Please direct queries to the corresponding author: Marie T. Ruel, IFPRI, 2033 K Street, N.W., Washington, D.C. 20006; e-mail: m.ruel@cgiar.org

Mention of the names of firms and commercial products does not imply endorsement by the United Nations University.

A summary of this work was presented in a poster at the Experimental Biology meetings in San Diego, California, USA, in 2003.

include a food aid component. In addition to their preventive health and nutrition activities, these programs distribute monthly take-home rations of fortified cereal blends, such as wheat-soy blend (WSB), corn-soy blend (CSB), and soy-fortified bulgur (SFB). These cereal blends are fortified with several vitamins and minerals (see Appendix 1 for nutrient composition) and are usually targeted to pregnant and lactating women and malnourished children under the age of five years. The World Vision, US Agency for International Development (USAID)-funded Title II Program in Haiti is one such program, which currently provides direct monthly food rations to malnourished children (8 kg of WSB or CSB and 2 kg of oil*) and to pregnant or lactating women (5 kg of SFB, 1.5 kg of oil, and 2 kg of lentils). In addition, the program provides one indirect food ration to families of beneficiaries to compensate for some of the intrahousehold sharing of commodities that naturally occurs with take-home rations.**

In spite of the popularity of Maternal and Child Health food aid programs in the developing world, the contribution of donated fortified cereal blends to the quality of young children's diets has rarely been assessed. The question addressed in this article is whether the donated fortified cereals provided as take-home rations by the World Vision Program can help infants and young children meet their daily nutrient requirements by significantly improving the nutrient density of their diet. In order to answer this question, we conducted a series of participatory recipe trials to assess current complementary feeding practices in one of the areas targeted by the program (the Central Plateau) and to develop new, improved recipes using a combination of locally available ingredients and foods, and donated fortified cereal blends.

Methods

Study area

This study was conducted in a total of 11 communities in the Central Plateau region of Haiti, comprising 6 lowland communities and 5 in mountainous areas. The regions and communities were selected to represent the different areas covered by a larger program evaluation, of which this substudy was a part [2]. All study communities were primarily rural. The lowland communities were generally accessible by road, and all were within 6 km from the main road. The main crops cultivated in these areas were staples such as corn, sorghum, beans, cassava, and sweet potatoes. The highland communities, on the other hand, were less accessible by road, more remote, and less densely populated and had more limited access to water and health services. Vegetable production was more common than staple food cultivation in the mountain areas. Our baseline survey in the intervention area revealed that 23% of children were stunted, 21% were underweight, and 5% were wasted [2].

Recipe trials

Recipe trials are participatory cooking sessions conducted with small groups of mothers and their children with the aim of developing special complementary foods for infants and young children. Specifically, recipes are prepared, tasted, and discussed to evaluate their acceptability, feasibility, and affordability for inclusion in the diets of young children [3]. This technique of developing enriched complementary foods that are based on locally known recipes as well as local ingredients has been used in a number of countries, with adaptations to each context [4–6].

In our study, the recipe trials were used to document the types of complementary foods usually prepared for young children in this population, their ingredients, and the mode of preparation. Thus, the recipe trials began with a recipe demonstration, conducted by the participants for the research team, to learn how infant foods were usually prepared. A group of mothers used their traditional preparation methods to demonstrate current recipes for various foods that had been previously identified as widely fed complementary foods: salt cracker gruel, bread soup, mashed plantain with fish sauce, and wheat flour gruel. This was followed by a three-step participatory process, which included the following activities:

1. *A first visit to prepare the trial with the group.* Specific activities included exploring potential improvements in currently fed complementary foods and discussing an array of suggested ingredients to enrich the complementary foods, creating new recipes, and preparing for the actual recipe trial. Public health programs in Haiti have traditionally used the concept of food groups to discuss dietary quality, and therefore this was a familiar concept for the participants in the recipe trial. The concept of "enrichment" of traditional recipes was also used to aid the discussion of potential candidate ingredients for improving the nutrient value of the traditional recipes.
2. *The recipe trial itself,* followed by a tasting session and feedback on the recipes, techniques of preparation,

* Donated oil is also fortified with vitamin A and E (see Appendix 1).

** The indirect food ration differs depending on whether the beneficiary is a malnourished child or a pregnant or lactating woman. When the beneficiary is a child, the indirect ration for the family includes 10 kg of WSB and 2.5 kg of lentils. When the beneficiary is a pregnant or lactating woman, the indirect ration includes 5 kg of WSB, 1.5 kg of oil, and 2 kg of lentils. When a family has two beneficiaries, only one indirect ration is provided, and the ration provided includes 10 kg of WSB and 2.5 kg of lentils.

perceived feasibility, and affordability.

3. *Follow-up visits* for feedback on home-based preparation of the improved recipes and the experience of feeding the improved recipes to children and other family members.

The complete three-step process was carried out in three project areas.* Specific question guides were developed to facilitate the collection and organization of information at each stage. The ingredients were either purchased by the participants in quantities they normally used and with cash assistance from the research team, brought from the participants' home gardens, or bought from local markets by the research team. In addition to bringing ingredients for the recipe trials, the participants provided other types of support, such as hosting the activity or providing the fuel and cooking utensils to prepare the recipes. The arrangements for these logistical issues were worked out by the participants themselves at step 1 of the recipe trials in each zone. Thus, the entire process was highly participatory and was owned by the women themselves. The research team served mainly to facilitate the process of development and discussion and to ensure that all steps were documented.

At the end of each recipe trial session, the participants and their children tasted the recipes that were prepared. Only children older than six months were included in the tasting sessions. Often, other neighbors and children assisted in the tasting sessions. Specific issues related to the acceptability of the recipe, the feasibility of home preparation under daily conditions, and the affordability of the recipe were explored by feedback interviews conducted at the end of the tasting session.

The final step of the recipe trials included a set of follow-up interviews with each group of participants, usually about two or three weeks after the recipe trial session (step 3). These interviews gathered data on which of the recipes had been prepared at home between the time of the recipe trial and the follow-up visit. The interviews explored the feasibility and affordability of the recipes as well as any problem that may have come up during the preparation or consumption of the recipes in the home setting of each participant. The interviews were also used to assess whether participants had adhered to the originally developed recipe or had made any further modifications to the recipes.

Finally, the data from all the recipe trials were combined for analysis of the feasibility, acceptability, and affordability of the various recipes developed by the group trials. The cost and nutrient content of each recipe were assessed, and the information was used to identify a list of promising recipes for promotion in the behavior change and communication (BCC) program. Analysis of the nutrient composition of the foods was performed with a software program called Food Processor 7.1 (ESHA) and utilized US Department of Agriculture food-composition values.

The protocol of the study was approved by the Cornell University Committee on Human Subjects.

Results

Complementary foods commonly fed to infants and young children

The mothers in our study traditionally prepared three types of complementary foods: cereal gruels with some type of fat (salt cracker gruel, and bread soup), cereal gruels with sugar but no fat (wheat flour gruel), and mashed plantain or manioc with a fish sauce. The main ingredients included in these gruels are presented in table 1. Two of the gruels were selected for modification during the recipe trials: the wheat flour gruel and the mashed plantain with fish sauce. The main reasons for choosing these two recipes were that they seemed more appropriate for enrichment because they already contained some basic energy- or nutrient-rich foods (such as fish or oil) or they were based on wheat flour, which could be replaced by donated fortified cereal blends such as WSB or CSB. The salt cracker and bread

* The three-step recipe trial process was conducted in the following rural zones of the Central Plateau of Haiti: Bassin Zim, with a group of two mothers and three grandmothers and their children and grandchildren (1–36 months old); Tierra Muscadi, with a mixed group of five mothers and three fathers and their children (1.5–11 months old); and Marmont, with a group of five mothers and their children (8–11 months old).

TABLE 1. Types of complementary foods traditionally fed to infants and young children in the Central Plateau of Haiti

Food	Main ingredients
Cereal gruels or soups with source of fat	
Salt cracker gruel (*bouillie de bon bon sel*)	Water, salt crackers, butter, sugar, salt
Bread soup (*soupe de pain)*	Water, bread, oil, spices, vegetables, salt
Cereal gruels with sugar, no fat	
Wheat flour gruel (*bouillie de farine France)*	Water, wheat flour, sugar, flavorings (vanilla or cinnamon)
Mashed plantain or manioc gruel with fish and fat (*banane écrasée*, *bouillie de manioc)*	Mashed plantain or manioc gruel with fish sauce (made with small amount of dried fish cooked in oil and water)

soups were not considered for modification, although they had high energy density, because they appeared to have very low nutrient density and offered little potential for improvement.

Modified recipes developed during the recipe trials

A total of 11 modified recipes were developed during the recipe trials. Table 2 summarizes information on the acceptability, perceived feasibility of preparation, and cost of the recipes, and the results of the follow-up interviews conducted to assess whether mothers had prepared the recipes at home. The most promising recipes from the point of view of cost, acceptability, and feasibility were gruels made from the fortified cereal blends with added fish or dry milk (table 2, recipes 8 and 9), or gruels made from wheat flour and enriched with the addition of beans and dried fish (recipe 3), beans and sugar (recipes 4 and 5), a beaten egg (recipe 10), or expressed breastmilk (recipe 11).

Mashed plantain preparations with pumpkin and fish sauce (recipes 6 and 7) were also well accepted, but they were among the most expensive recipes. When plantains are in season, however, the cost of these recipes is reduced by at least 7 gourdes (US$0.25)* for families who grow them, and thus the recipes become much more affordable.

The use of beans in the recipes, although culturally and nutritionally desirable, adds considerably to the number of preparation steps and the time involved, because beans need to be processed by roasting, removing the skin, and powdering. This may considerably reduce the likelihood that mothers will prepare these recipes daily. However, because they were very popular in terms of taste and child acceptance, they can still be promoted for preparation, albeit on a less frequent basis.

On the whole, the improved recipes required approximately the same preparation time as the traditional recipes (the wheat-based and plantain-based traditional recipes took 25 and 35 minutes to prepare, respectively). As expected, both traditional recipes were cheaper than most of the improved recipes, because they included less ingredients: the wheat-based traditional recipes cost about 5.35 gourdes (US$0.19) and the plantain-based recipes 11 gourdes (US$0.39).** The cost of the improved CSB-based recipes, however, was very similar to the cost of the traditional wheat-based preparations and almost half the cost of the traditional mashed plantain-based recipes (for households that had to purchase the plantains).

One potential constraint on the sustained use of most enriched recipes is that these gruels are generally prepared for the entire family, and therefore, preparing an enriched product entails a much higher cost than simply adding small amounts of high-quality foods to the child's portion. The option of adding ingredients such as an egg, powdered milk, or expressed breastmilk to the child's gruel seems a good alternative, and women responded positively to the suggestion to prepare these enriched porridges only for the youngest members of the family.

With regard to cost, the cheapest improved preparations are, as expected, those based on the use of donated cereal blends, because the main ingredients (the flours and the oil) are donated by the program. The next cheapest preparation is the wheat flour gruel with an added egg. This preparation is cheaper than wheat flour gruel with black beans and dried fish, or black beans and sugar, and is clearly cheaper than all preparations that include a source of fish. In terms of acceptance and energy density, this preparation is also a good choice (see below). Even if the fish preparations are more expensive, the unique nutrient composition of fish is worth the effort of trying to promote its consumption at least once or twice a week if families can afford it.

Nutritional quality of the complementary foods

Our analysis of the nutritional quality of the currently fed complementary foods and the modified recipes is based on the assessment of their energy and micronutrient density, according to current World Health Organization (WHO) recommendations for complementary feeding of the breastfed child [1, 7]. Thus, the ability of the complementary foods to help children meet their requirements of energy and selected micronutrients (iron, zinc, and vitamin A) at different ages was assessed by comparing the energy and nutrient content of selected complementary foods with current recommendations.***

Energy density

The current WHO recommendations suggest that infants between 6 and 8 months of age should receive at least 200 kcal/day from complementary foods [1]. For 9- to 11-month-old infants, the amount of energy from complementary foods should be 300 kcal/day,

* At the time of the study, the exchange rate was 28 gourdes—US$1.00.

** The per capita gross domestic product in Haiti in 2001 was estimated at $447 (http://unstats.un.org/unsd/demographic/social/inc-eco.htm; accessed September 12, 2004).

*** For wheat flour, we used the nutrient composition values for nonfortified wheat flour, because our interviews at the main flour mill in Port-au-Prince, which controls 80% of the market in Haiti, indicated that fortification was irregular. When fortified, wheat flour should contain 3.7 mg of iron/100 g of flour. Information about the type of iron fortificant used was not available, however, and thus the bioavailability of iron in the fortified flour is unknown.

TABLE 2. Improved recipes tested in recipe trials

No.	Name	Comments on recipe: From discussion after recipe trial: Acceptability	Comments on recipe: From discussion after recipe trial: Feasibility (no. of steps, preparation time)	Comments on recipe: From discussion after recipe trial: Cost (gourdes)[a]	Comments on recipe: From follow-up interviews: Whether the recipe was actually tried at home, and feasibility of sustained preparation
Millet-based					
1	Millet gruel with black beans and groundnuts	Very good	10 steps, 45 min	11.5	Yes. However, cost of beans and time-consuming recipe were constraints
Wheat flour-based					
2	Wheat flour gruel with black beans and groundnuts	Very good	7 steps, 25 min	11	No. Cost of beans and time-consuming recipe were constraints
3	Wheat flour gruel with black beans and dried fish	Less liked than sweet version; considered too thick for a 6-month-old	4 steps, 35 min	9.25	Yes. All women tried it. However, they felt that the children liked the sweet version more
4	Wheat flour gruel with black beans and sugar	Good; considered too thick for a 6-month-old	4 steps, 35 min	8.25	Yes. All women tried it. Well accepted by children
5	Wheat flour gruel with black beans, sugar, and oil	Good, consistency fine too	4 steps, 35 min	11.25	Only 2 of 5 women tried it. Lack of money to buy beans and time for preparation
Mashed plantain-based					
6	Mashed plantain with pumpkin and fish sauce	Good	2 steps, 35 min	13	Yes. All women tried it. Well accepted by children.
7	Mashed plantain with pumpkin and fish sauce	Excellent	2 steps, 35 min	17.5	3 of 5 women tried it. Well liked. Lack of availability of pumpkin in market was a constraint; can be prepared when pumpkins are available in gardens
CSB-based					
8	CSB gruel with dried fish	Good	2 steps, 20 min	6	Follow-up interviews not done, but can be considered feasible because major ingredients (CSB/WSB and oil) are donated by the program
9	CSB gruel with dried milk and sugar	Very good	1 step, 15 min	6	
Other recipes					
10	Addition of an egg to the wheat flour gruel	Good	1 step, 35 min	6.25	2 of 5 women tried it. Well liked by children
11	Addition of expressed breastmilk to the gruel	No information	Depends on which gruel	Cost of gruel	All lactating women in the group tried it. Well liked by children

a. 28 gourdes = US$1.00.

and for 12- to 23-month-old children, it should be 550 kcal/day. These guidelines are based on children with average energy requirements receiving average amounts of breastmilk at each age [7]. If infants and young children consume more or less breastmilk than average, the amount of energy required from complementary foods will differ accordingly. These recommendations also assume good maternal nutritional status and adequate breastmilk intake and composition of breastmilk.

The number of times infants and young children should be fed complementary foods depends on the average energy density of their diet (kilocalories per gram of main complementary food) and the amount they consume at each meal. The recently developed *Guiding Principles for Complementary Feeding of the Breastfed Child* [1] recommends that complementary foods have a minimum energy density of 0.8 kcal/g and that they be fed two or three times a day to infants 6 to 8 months of age, and three or four times a day to infants and children 9 to 11 months and 12 to 24 months.

Table 3 presents the energy density (kcal/g) of the currently fed complementary foods as well as of the modified recipes developed during the recipe trials. Also, using information on average serving sizes used at different ages, as assessed during the discussions that followed each recipe trial,* the table presents the number of servings of each of the gruels that would be needed to meet the energy needs of children in different age groups.

Note that all recipes, including the traditional ones, meet the minimum requirement of 0.8 kcal/g. The salt cracker gruel has the highest energy density of all complementary foods, whereas the bread soup, wheat flour gruel, and improved mashed plantain preparations have the lowest energy densities. It is interesting to note that the original preparation of mashed plantain with fish sauce is actually more energy dense than the modified recipes. This is because of the larger amount of vegetable oil used to prepare the accompanying fish sauce in the original preparation in one area (Bassin Zim), compared with the modified recipes of the same dish prepared in other areas (Marmont and Tierra Muscadi). It may be advisable to retain the amount of fat used in the original recipe to increase the energy density of the improved preparation. It is important to remember, however, that higher energy density resulting from additional oil results in lower density of protein and micronutrients, and therefore the approach should be used cautiously.

The last three columns of table 3 present the number of servings of each complementary food that would be required to meet the daily energy needs of infants and children 6 to 8, 9 to 11, and 12 to 23 months old.

* Mothers reported that on average 6- to 8-month-old infants usually consumed ½ cup of the gruels or mashed plantain or manioc preparations, 9- to 11-month-old infants about ¾ cup, and 12- to 23-month-old children 1 cup. Based on these serving sizes and the energy densities of the different complementary foods, we computed the number of servings of each preparation that would need to be consumed by children of different ages in order to meet their daily energy requirements [7].

TABLE 3. Energy density of traditional and modified recipes, and number of daily servings required to meet breastfed children's daily energy requirements

No.	Name	Energy density (kcal/g)[a]	No. of daily servings[b] required according to age		
			6–8 mo	9–11 mo	12–23 mo
	Traditional recipes				
1	Salt cracker gruel	2.40	0.7	0.7	0.9
2	Bread soup	0.87	1.9	1.9	2.6
3	Wheat flour gruel	0.90	1.9	1.9	2.6
4	Mashed plantain with fish sauce	2.10	0.9	0.9	1.2
	Modified recipes				
1	Millet gruel with black beans and groundnuts	0.96	1.6	1.6	2.2
2	Wheat flour gruel with black beans and groundnuts	0.97	1.6	1.6	2.2
3	Wheat flour gruel with black beans and dried fish	1.55	1.0	1.0	1.4
4	Wheat flour gruel with black beans and sugar	1.28	1.2	1.2	1.7
5	Wheat flour gruel with black beans, sugar, and oil	1.11	1.4	1.4	1.9
6	Mashed plantain with pumpkin and fish sauce	0.80	2.1	2.1	2.9
7	Mashed plantain with pumpkin and fish sauce	0.87	1.8	1.8	2.5
8	CSB gruel with dried fish	1.25	1.2	1.2	1.7
9	CSB gruel with dried milk and sugar	1.44	1.0	1.0	1.4
10	Addition of an egg to the wheat flour gruel	1.36	1.0	1.0	1.3

a. The minimum energy density recommended for complementary foods for breastfed children 6–23 months of age is 0.08 kcal/g [1].

b. The average serving sizes for children 6–8, 9–11, and 12–23 months were estimated during recipe trials to be ½ cup, ¾ cup, and 1 cup, respectively. The number of servings recommended at 6–8, 9–11, and 12–23 months are: 2–3, 3–4, and 3–4, respectively [1].

Note that all calculations presented in this table are based on assumptions of *average* energy intake from breastmilk and average energy requirements [7]. As expected, gruels of greater energy density would require a smaller number of feedings per day, whereas the lower-density preparations would require greater feeding frequency. The salt cracker gruel, for example, which has the highest energy density, would need to be fed about once daily (0.7–0.9 servings, depending on age), whereas the bread soup, wheat flour gruel, and improved mashed plantain preparations, which are of lower energy density, would have to be fed two or three times daily. Table 3 shows that, across all age groups, none of the preparations exceed the recommended feeding frequency, suggesting that in general the feeding frequencies required for children given the traditional or improved preparations are not excessive. Thus, it appears that the energy densities of commonly fed complementary foods in this population are generally acceptable.

Vitamin A, iron, and zinc density

Vitamin A, iron, and zinc are critical micronutrients for the growth, development, immunity, and health of infants and young children and are known to be limiting nutrients in the diets of infants and young children [7]. The micronutrient density of complementary foods is usually expressed in terms of the amount of the nutrient per 100 kcal of the complementary food. Table 4 shows the average densities of vitamin A, iron, and zinc in the traditional and improved recipes, compared with the average recommended micronutrient densities of complementary foods at specific ages (see table headers). Note that the recommended densities for all three micronutrients decrease markedly as the infant becomes older and enters the second year of life; this is especially true for iron. The recommended iron density of complementary foods for infants 6 to 8 months of age is 7.7 mg/100 kcal for diets of low iron bioavailability, compared with 4.6 mg/100 kcal and 1.6 mg/100 kcal for children 9 to 11 and 12 to 23 months of age, respectively. Note also that the recommended iron density of complementary foods is, as expected, lower for diets in which the bioavailability of iron is average than in those in which iron bioavailability is low (see numbers in parentheses in table headers). In this analysis, we consider all recipes to have low iron bioavailability, unless they include fish (traditional recipe 4 and modified recipes 3, 6, and 7) and/or CSB, which contains vitamin C, a promoter of iron absorption (modified recipes 8 and 9), in which case they are considered to have average iron bioavailability.

The data show that none of the traditional recipes met the recommended nutrient densities for vitamin A, iron, or zinc. The improved preparations that contained even small amounts of pumpkin or an egg, however, achieved higher vitamin A densities than those recommended for all three age groups (see bolded numbers in table 4). The use of CSB, which is fortified with vitamin A, was also an excellent alternative to increase the vitamin A density of the recipes. As shown in table 4, both recipes containing CSB had vitamin A densities more than three times higher than current recommendations.*

The densities of iron and zinc, which are considered “problem” nutrients in infants and young children in developing countries who do not receive fortified foods, are tremendously inadequate for the 6- to 8-month age group in all our recipes, whether traditional or improved [1]. Although adding an egg to the wheat flour gruel almost doubled the iron and zinc content of the usual recipes, and adding dried fish to the wheat flour and bean gruel increased their zinc density, all modified recipes still had grossly inadequate iron and zinc densities for 6- to 8-month-old infants. The complementary foods made with CSB (the fortified food aid commodity) had significantly more iron and zinc than the other recipes. Moreover, the bioavailability of iron can be assumed to be average, as opposed to low, for these recipes (8 and 9), because CSB is also fortified with vitamin C. Even with average bioavailability, which decreases the recommended iron density of complementary foods to 4 mg/100 kcal for 6- to 8-month-old children, and with the addition of feasible and acceptable levels of fish in recipe 8, the CSB-based recipes still did not reach the recommended iron density of complementary foods for this age group. The same was true for zinc density, which was only about half the recommended density for this age group in both preparations that included CSB. Zinc densities in the gruels prepared with CSB were also too low for 9- to 11-month-old children, although iron densities were adequate for this age group if the assumption of average iron bioavailability was used.

The situation was markedly different for children in their second year of life; for these children, the two CSB-based recipes achieved appropriate iron and zinc density, and for iron, this was true whether low or average bioavailability was assumed. The recommended iron densities for 12- to 23-month-old children are 1.6 and 0.8 mg/100 kcal for low and average iron bioavailability, respectively; the CSB gruels contained 3.20 mg of iron per 100 kcal (recipe 8 containing fish) and 2.5 mg of iron per 100 kcal (recipe 9 containing dry milk).

Thus, fortified cereal blends such as CSB could contribute significantly to improving the quality of the complementary foods given to Haitian children

* Although the donated oil is fortified with vitamins A and E, we used the nutrient composition of nonfortified oil in our calculations of the nutrient density of the preparations. This is because the donated oil constitutes only a small proportion of all the oil used by families, and other oils available in the market are not fortified.

in their second year of life. The use of CSB was key to allowing the diets of 12- to 23-month-old children to reach the recommended densities of three main problem nutrients: vitamin A, iron, and zinc. This was not the case for children under one year of age, who would need complementary interventions to help them meet their iron and zinc requirements.

In the following section, we assess the potential contribution and feasibility of one such strategy—using red meat or liver—to complement the diets of six- to eight-month-old infants and to help them fill their iron and zinc gaps.

Cost and feasibility of using red meat or liver in the diets of six- to eight-month-old infants

To determine whether it would be feasible to promote increased intake of red meat (beef) or liver to fill the

TABLE 4. Summary of the vitamin A, iron and zinc densities of traditional and enriched recipes

		Density (amount /100 kcal of recipe)		
No.	Name	**Vitamin A** (µg RE) *Recommended densities*[a] 6-8 mo: 31; 9–11 mo: 30; 12–23 mo: 23	**Iron** (mg) *Recommended densities*[a] 6–8 mo: 7.7[b] (4.0)[c]; 9–11 mo: 4.6[b] (2.4)[c]; 12–23 mo: 1.6[b] (0.8)[c]	**Zinc** (mg) *Recommended densities*[a] 6–8 mo: 1.6; 9–11 mo: 1.1; 12–23 mo: 0.6
Traditional recipes				
1	Salt cracker gruel	0	0.93	0.14
2	Bread soup	13.02	0.72	0.05
3	Wheat flour gruel	0.03	0.41	0.13
4	Mashed plantain with fish sauce	0.66	0.16	0.05
Modified recipes				
1	Millet gruel with black beans and groundnuts	0.12	1.35	0.18
2	Wheat flour gruel with black beans and groundnuts	0.12	0.50	0.26
3	Wheat flour gruel with black beans and dried fish	0.19	0.61	0.35
4	Wheat flour gruel with black beans and sugar	0.17	0.68	0.28
5	Wheat flour gruel with black beans, sugar, and oil	0.21	0.73	0.31
6	Mashed plantain with pumpkin and fish sauce	**46.20**[d]	0.49	0.17
7	Mashed plantain with pumpkin and fish sauce	**40.55**	0.49	0.24
8	CSB gruel with dried fish	**140.50**	3.20	0.90
9	CSB gruel with dried milk and sugar	**111.00**	2.50	0.70
10	Addition of an egg to the wheat flour gruel	**42.55**	0.86	0.34

a. Recommended nutrient densities are for infants who consume average amounts of breastmilk [7].
b. Assuming low bioavailability of iron [19].
c. Assuming medium bioavailability of iron (numbers in parentheses) [19].
d. Boldface numbers indicate that the recipe meets the recommended nutrient density for all three age groups.

iron and zinc gaps, we calculated the amounts of these products that would be required to enable young infants six to eight months old to meet their daily requirements of these nutrients. We assumed that the infants were consuming gruels twice a day, which is the minimum recommended feeding frequency for this age group. We used the WHO recommended daily intakes of iron and zinc for infants obtaining the average amount of energy from breastmilk [8]. The *absorbed* iron requirements of infants between six and eight months are estimated to be about 1 mg/day, and the recommended intake of iron varies, depending on the bioavailability of the sources of iron in the diet [7]. The recommended zinc intake for the same age group is 4.1 mg/day (no correction for bioavailability is available). Since meats contain heme iron, which is highly bioavailable compared with the iron in cereals, calculating the amount of meat needed to fill the iron gap requires consideration of the difference between the amount of iron absorbed from meat and the amount absorbed from cereal-based gruels.

Table 5 presents the amounts of beef and beef liver that would be needed to fill the iron gap that remains after children have been fed the enriched gruels made with either fortified food aid commodities or unfortified wheat flour. The calculations are made separately, depending on whether the meat products are fed at the same meal as the gruel or not. The reason for making this distinction is that meat products have been shown to enhance absorption of the nonheme iron contained in plant-based foods when consumed at the same meal [9, 10].

In all calculations, we use an iron requirement of 1 mg of *absorbed* iron [7]. We assume a high bioavailability of iron from beef and liver (15%), a medium bioavailability of iron from gruel consumed at the same

TABLE 5. Amounts and price of beef and beef liver that would have to be consumed by children six to eight months old to complement selected gruels fed twice a day to fulfill their requirements for iron[a]

Beef or beef liver is eaten at a different meal from the gruel					
		Beef		Beef liver	
Gruel	Iron absorbed from gruel[b] (mg)	Amount needed (g)	Price (gourdes)	Amount needed (g)	Price (gourdes)
CSB gruel with dried fish	0.88	20	2	16	2
CSB gruel with sugar and milk	0.59	56	5.5	45	6
Wheat flour gruel with beans and fish	0.20	102	10	83	12
Wheat flour gruel with beans and sugar	0.13	110	11	90	13
Beef or beef liver is eaten at the same meal as the gruel					
		Beef		Beef liver	
Gruel	Iron absorbed from gruel[c] (mg)	Initial amount + additional amount needed (g)	Price of total amount[d] (gourdes)	Initial amount + additional amount needed (g)	Price of total amount[d] (gourdes)
CSB gruel with dried fish (salty)	1.56	20 + 0	2	20 + 0	3
CSB gruel with sugar and milk (sweet)	1.10	20 + 0	2	20 + 0	3
Wheat flour gruel with beans and fish	0.36	20 + 43	6	20 + 18	5.6
Wheat flour gruel with beans and sugar	0.25	20 + 57	8	20 + 30	7

CSB, Corn-soy blend.

a. Absorbed iron requirements for infants 6–8 months old = 1.05 mg (calculated from iron intake requirements) [7]. Exchange rate at the time of the study: 1 US$ = 28 gourdes.

b. Assuming that 10 g of beef or beef liver is fed twice daily at a different meal than the gruel. Bioavailability assumptions: low (6%) for sweet CSB and wheat flour gruels; low to medium (8.5%) for CSB and wheat flour gruels containing dried fish.

c. Assuming that 10 g of beef or beef liver is fed twice daily along with ½ cup of gruel. Assumptions about *increase* in bioavailability with addition of red meat: Increase from low (6%) to medium (11%) with addition of red meat to low-bioavailability gruels, increase from low-medium (8.5%) to high (15%) with the addition of red meat to low- to medium-bioavailability gruels [10].

d. The total price of beef/beef liver here includes the price of the 20 g fed at the same meals as the gruel + the cost of the additional beef or beef liver needed to close the iron gap.

time as meat (11%), and a low bioavailability of iron from gruel consumed without meat (6%) (see details of calculations in Appendix 2).

The findings presented in table 5 show that infants fed improved gruel recipes made of fortified CSB would still need between 20 and 60 g/day of beef or between 15 and 45 g/day of beef liver in order to close their iron gap (assuming that meat is *not* consumed at the same meal as gruels), depending on whether the gruels consumed included dried fish or not. If nonfortified cereals such as wheat flour were used to prepare the gruels, almost twice that amount of meat or liver, i.e., about 100 g, would be required for infants to meet their daily requirements of absorbable iron.

By contrast, even as little as 10 g of beef or liver, if consumed at the same time as each serving of the fortified gruel—for a total of 20 g of beef or beef liver per day—would be sufficient to completely close the iron gap for infants in this age range who consume CSB-containing gruels. It is important to remember, however, that these amounts of meat or liver would have to be consumed by the six- to eight-month-old infant in addition to the two servings per day of ½ cup of enriched porridges, some of which already contain fish. It may be impossible to feed such large amounts of food to young infants, who have limited gastric capacity. The organoleptic characteristics of meals containing meats and gruels are also an issue of concern. Finally, the cost of meat products may be prohibitive in the long run for poor Haitian families. Even if mothers were to purchase only the amounts required for a six- to eight-month-old infant, the cost of beef or beef liver would range from 2 to 14 gourdes (US$0.07–0.50). This may be affordable on an occasional basis, but certainly not on a daily basis in a situation where the average income is under a dollar a day. Consuming the meat products at the same meal as other sources of nonheme iron would slightly reduce the cost, especially if donated fortified cereal blends were used (these have the double advantage of being fortified and free). This option may therefore be more feasible for beneficiary families, but again, only under the conditions that meat and organ meats are readily available in the markets, mothers are able to purchase them in small quantities, and mothers are willing and able to use them only for their young infants.

Meeting zinc requirements by the addition of some animal products to the diet seems more feasible than meeting iron requirements in this way, both in terms of the amounts required and the cost (the amounts range between 19 and 55 g and the costs between 2 and 5.5 gourdes, or US$0.10–0.20) (results not shown). These costs, however, are still significant for poor families, and thus, alternative or complementary solutions to enhance the iron and zinc content of young children's diets should be given serious consideration.

Program implications

Summary of findings

Our research shows that it is feasible to markedly improve the nutritional quality of complementary foods in poor rural areas of Haiti by using a combination of donated fortified cereal blends and locally available foods. Significant improvements in the concentrations of vitamin A and zinc could be obtained by including CSB and/or acceptable and affordable amounts of black beans, groundnuts, pumpkin, dried fish, milk, or eggs in the preparations. Only preparations containing CSB, however, could achieve the recommended concentrations of iron and zinc in complementary foods, and even this was achievable only for 12- to 23-month-old children. For infants, and especially those between 6 and 8 months of age, the high densities of iron and zinc recommended in complementary foods for this age group could not be achieved, even when fortified CSB and other locally available, acceptable, and affordable foods were combined. The same was true for the recommended zinc density of complementary foods among 9- to 11-month-old children, which could not be fully achieved even with fortified CSB.

It is important to note that these findings probably represent a "worst-case scenario," because we generally used conservative bioavailability assumptions for iron, and we did not correct for the fact that iron absorption increases with poor iron status. The recent Demographic and Health Survey in Haiti indicates that approximately 50% of children in this age group are anemic; thus, we can assume that a large proportion of children are iron deficient and likely to absorb more iron than non-iron-deficient children.

Using our conservative assumptions for iron bioavailability, our findings show that in this population, fortified cereal blends were key to achieving the recommended vitamin A, iron, and zinc densities of complementary foods for children 12 to 23 months of age, but they were not sufficient for infants. Among infants under one year of age, the presence of CSB brought the density of vitamin A in complementary foods to the recommended levels, but did not do the same for zinc and iron. Thus, complementary approaches are needed to ensure the adequate iron and zinc density of complementary foods for infants younger than 12 months in resource-constrained environments such as rural Haiti.

One such strategy, which was explored in the present study, is to complement the diet with animal flesh foods such as red meat or liver. The need to use animal-source foods to improve the nutritional quality of complementary foods, however, immediately raises concerns about the availability and access of poor rural families to these products. Our research suggests that although cultural factors do not seem to be a constraint to including animal-source foods in young children's diets in this population [11], economic barriers are fundamentally limiting. Families may have difficulty purchasing even the relatively small amounts of meat products required to feed their young infants on a regular basis, let alone the amounts that would be required if they were to use meat products in food preparation for the whole family. As is the case in many cultures, Haitian mothers cannot conceive of purchasing special nutrient-rich (and expensive) foods only for their young children, especially when they have several other children who would benefit from improved dietary quality. Moreover, even if a mother could be persuaded to purchase small amounts of meat products for her youngest, most vulnerable child, our market study showed that liver, in particular, is largely unavailable for sale in small quantities in local markets [11].

Finally, an additional constraint to using animal-source foods to improve young children's intakes of bioavailable iron and zinc is the issue of feasibility, i.e., whether young children can actually consume the required amounts of meat products at the required frequency. Infants and young children have limited gastric capacity as well as developmental constraints that may prevent them from being able to consume meat products, especially in environments where food processors or other tools to make pureed foods are unavailable. Furthermore, there could be organoleptic constraints to feeding gruels and beef or liver at the same time, particularly at an age when infants are only beginning to experience different tastes and textures. Thus, although meat products can significantly contribute to improving the quality of young children's diets, especially with regard to bioavailable iron and zinc, it is important to recognize their limitations.

In summary, our results confirm that both donated fortified cereal blends and meat products have great potential to improve the nutritional quality of complementary foods. For infants 6 to 11 months of age, however, neither one of these approaches is sufficient. The fortified cereals do not have sufficiently high levels of iron and zinc fortificants to completely close the iron and zinc gaps in these young children, and the regular use of meat products is likely to be economically and practically unfeasible in poor environments. Combining the two approaches is clearly worth exploring, but additional recipe trials will be needed to explore the possibility of developing complementary foods based on fortified cereal blends and meat or organ meat for this age group, in different cultures.

Iron and zinc fortification levels of donated fortified cereal blends

The nutrient composition of donated fortified cereal blends used in the World Vision-Haiti Program is presented in Appendix 1. Compared with other processed complementary foods designed for infants and young children in Latin America, the iron content of WSB and CSB (17.5–18 mg/100 g) is average, while the zinc content (5.5–5 mg/100 g) is low [12]. For instance, in the nine products compared by Lutter [12], the iron concentration ranged from 10 to 23 mg/100 g of dry products, whereas the zinc concentration ranged from 5 (in CSB) to 23 mg/100 g (in a product developed in Mexico). Unfortunately, the table comparing the nine products does not include any information on the iron compound used in the fortification process, and thus it is impossible to assess the bioavailability of iron in these foods.

For CSB and WSB, the iron fortificant is ferrous fumarate [13], which has good bioavailability (as high as that of ferrous sulfate) [14]. Corn-soy blend and WSB also contain 40 mg of vitamin C per 100 g, which increases the absorption of nonheme iron. It is not clear, however, how much of this vitamin C remains after the CSB has been cooked and, therefore, what its ultimate contribution to increasing nonheme iron bioavailability is. For zinc, although the levels are lower than the levels found in other complementary foods in Latin America [12], they are consistent with current recommendations for processed complementary foods of 4 to 5 mg per 100 g of dried product [15]. Overall, it appears that the current iron and zinc fortification levels of CSB (and WSB) are generally acceptable, and our findings confirm that they are sufficient for children in their second year of life, who consume them in the recommended frequency and quantity. For infants, however, these levels are still too low, and therefore complementary strategies need to be considered, such as the use of supplements or home fortification with micronutrient sprinkles, spreads, or dispersible tablets. Increasing the fortification levels of cereal blends could also be an option, but potential toxicity or negative interactions between micronutrients has to be carefully considered before implementing such measures. It is also important to recognize that donated cereal blends are not used only as complementary foods—on the contrary, they are often widely shared among all family members—and therefore their fortification levels have to be safe for all age groups, including those who may consume relatively large amounts of the products. Combining approaches—such as using donated fortified foods, including some amounts of meat in the diet, and possibly using home fortification methods such as sprinkles, spreads, or dispersible tablets—will be necessary to ensure that the iron and zinc requirements of infants and young children are met.

Size of the monthly rations

We calculated the amount of CSB that would be required on a monthly basis to feed children under 24 months of age the average age-specific amount of the gruel twice a day. For infants 6 to 8 months old who usually consume approximately ½ cup of the gruel per serving, approximately 1.7 kg/month would be needed, whereas for 12- to 23-month-old children who consume on average one cup per serving, 3.4 kg/month would be required. Thus, the current amount of WSB of 8 kg/month (similar to CSB) for the direct ration is largely sufficient to cover the energy requirements of the target child, on the assumption that families also invest in additional ingredients to complement the energy content of the gruels. Clearly, continued efforts should be made to ensure that the WSB or CSB commodities are used primarily for the target children, although some sharing among family members would be acceptable in the case of the World Vision Program, because the size of the monthly ration is more than twice the amount required for a child under two years of age.

Recommendations for food aid programs

One of the key objectives of food aid programs targeted to young children is to reduce childhood malnutrition. In order to achieve this objective, packages of integrated nutrition and health interventions have been developed, which usually include several preventive interventions such as immunization, selected micronutrient supplementation, deworming, distribution of oral rehydration salts, and health and nutrition education, in addition to the distribution of food aid commodities. Food is used in these programs as a means to help alleviate one of the main constraints to adequate child-feeding practices, household food insecurity. Food rations, however, are but one of several approaches needed to improve complementary feeding practices. At least equally important is to teach families how to use the food supplements for the targeted beneficiaries, and our study is an example of how this can be done using participatory research methods. Based on our experience, we offer the following recommendations to food aid programs:

1. Food aid programs should conduct participatory, context-specific research to develop feasible, affordable, and culturally acceptable recipes using the food aid commodities distributed, combined with other locally available and affordable foods and ingredients.

The recipes should be developed on the basis of existing cultural patterns and the types of preparations used locally. The recipes should also be developed specifically for the age group targeted, e.g., infants and young children, or pregnant or lactating women. Within a country, the recipe trials should be conducted in different ecological zones with varying food systems as well as among populations with different dietary patterns. Well-designed and detailed step-by-step written materials are available to guide the design of formative research to assess current practices and the development of improved complementary feeding practices using methods such as focused ethnographic studies [16] and Trials of Improved Practices [3]. Successful programmatic experience with adapting these techniques to develop enriched complementary foods based on locally known recipes and locally available ingredients has also been documented in a number of countries [4–6].

2. Food aid programs should include intense promotional and educational efforts to ensure that the specially fortified cereal blends, such as CSB and WSB, are used primarily for the targeted beneficiaries (e.g., infants and young children, or pregnant or lactating women) who have higher nutrient requirements than other members of the household.

There is ample, although largely anecdotal, evidence that sharing of donated food commodities among family members is an unavoidable scenario in food aid programs. Some programs, such as World Vision in Haiti, have attempted to address this by providing an indirect food ration to be shared among family members, in addition to the direct food ration for the targeted beneficiary. At a given level of resources, this approach involves providing significantly larger amounts of food to a smaller number of beneficiaries and their families, and thus results in lower coverage. The approach, however, may still be more cost-effective than providing a single direct ration if leakage among family members is unavoidable, because it may ensure that the targeted beneficiary actually receives a greater share of the donated food commodities.

An additional approach used by the World Vision Program in Haiti is to provide different food commodities in the direct and indirect rations. More highly fortified products, such as CSB and WSB, are intended for the beneficiary child or mother, whereas other less fortified (or nonfortified) products, such as SFB and lentils, are provided for other family members. Although a theoretically sound approach, it is unlikely to be successful if the program does not include a strong educational intervention to teach recipients about the appropriate use of the different commodities for different household members.

Thus, in programs where both direct and indirect rations are used, and especially where higher-quality foods are provided for targeted beneficiaries, recipe trials and promotional efforts should focus on developing special preparations for the targeted beneficiaries using these products. This would ensure that the program achieves its objective of enhancing the nutrient intake and dietary quality of these more vulnerable household members. In the case of Haiti, for example, mothers should be sensitized to the fact that the WSB and CSB are intended for use as "special foods" for the young targeted child, while the other food commodities are provided specifically to complement the diets of other family members. Clearly, these concepts may be culturally unacceptable and impractical for mothers who have many mouths to feed and little time to do so. However, given the potentially important nutritional contribution of WSB and CSB at their current levels of fortification, it is crucial that programs ensure the appropriate use of these commodities in order to achieve a nutritional impact on their primary target. To our knowledge, no information is available on the effectiveness of such promotional efforts, but our evaluation of the World Vision Program in Haiti should shed some light on these issues.

3. Programs need to develop links with other types of interventions to improve the micronutrient density of complementary foods, and especially their iron and zinc concentrations. These include linking up with new initiatives, such as the promotion of increased availability, access, and intake of animal-source foods, or the use of home fortification with micronutrient sprinkles, spreads, or dispersible tablets.

As indicated previously, most maternal and child health programs with a food aid component provide a number of preventive nutrition and health interventions, including vitamin A and/or iron supplementation programs. Links with other, possibly more sustainable approaches, such as promoting greater intake of animal-source foods by young children, should also be established. In order to be successful, however, economic, cultural, and child developmental constraints to increasing the intake of animal-source foods among young children must be understood, and effective interventions to alleviate them should be designed. New initiatives are currently under way to develop strategies to improve household availability and access to animal-source foods and to promote their use in complementary foods for infants and young children. Simple technologies and tools to process meat products into purees in resource-constrained environments also need to be developed to facilitate their incorporation in young children's diets.

Finally, "home fortification," which consists of the direct addition of micronutrient sprinkles, spreads, or dispersible tablets to fortify young children's foods, is becoming increasingly popular. Although the efficacy of these approaches has been demonstrated in a few studies [17, 18], more research is needed to document their feasibility and effectiveness. The feasibility and acceptability of distributing micronutrient sprinkles for children 6 to 23 months of age along with the food rations in the World Vision-Haiti Program is currently being explored.

Conclusions

Poor complementary feeding practices continue to be a major bottleneck to reducing malnutrition in developing countries. It is thus imperative that existing resources, such as fortified food aid commodities, be used more effectively to contribute to improving the overall quality—and not only the quantity—of complementary foods for infants and young children. To achieve this, food aid programs should prioritize and strengthen their promotional and educational strategies to better educate program recipients in the optimal use of fortified food commodities, especially for targeted beneficiaries, i.e., pregnant or lactating women and infants and young children who have high nutrient requirements. Food aid programs should also strengthen their links with other initiatives to improve complementary feeding practices, including programs for the control of micronutrient deficiencies and interventions to improve the availability of and access to nutrient-rich foods. Finally, the vulnerability and excessively high nutrient requirements of infants in their first year can never be overemphasized, and packages of complementary interventions should be implemented in a timely manner to effectively reach infants during these critical few months of their life.

Acknowledgments

This research was made possible by the financial support provided to the Food and Nutrition Technical Assistance (FANTA) Project by the US Agency for International Development (USAID) under a cooperative agreement with the Academy for Educational Development (AED). Additional funding was provided by World Vision-Haiti, the Government of Germany, and the World Food Programme.

References

1. PAHO/WHO. Guiding principles for complementary feeding of the breastfed child. Washington, DC: Pan American Health Organization/World Health Organization, 2003.
2. Menon P, Ruel MT. Child care, nutrition and health in the Central Plateau of Haiti: the role of community, household and caregiver resources. Report of the IFPRI-Cornell University-World Vision baseline survey, Haiti 2002. Washington, DC: Food and Nutrition Technical Assistance (FANTA) Project, 2003.
3. Dickin K, Griffiths M, Piwoz E. Designing by dialogue. A program planner's guide to consultative research for

improving young child feeding. Washington, DC: SARA Project, Academy for Educational Development (AED), 1997.

4. Bentley ME, Dickin KL, Mebrahtu S, Kayode B, Oni GA, Verzosa CC, Brown KH, Idowu JR. Development of a nutritionally adequate and culturally appropriate weaning food in Kwara State, Nigeria: an interdisciplinary approach. Soc Sci Med 1991;33:1103–11.
5. Kanashiro HC, Fukomoto M, Bentley ME, Jacoby E, Verzpsa C, Brown KH. Use of recipe trials and anthropological techniques for the development of a home-prepared weaning food in the Central Highlands of Peru. J Nutr Educ 1991;23:30–5.
6. Piwoz E. Improving feeding practices during childhood illness and convalescence: lessons learned in Africa. Washington, DC: SARA Project, Academy for Educational Development (AED), 1994.
7. Dewey KG, Brown KH. Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs. Food Nutr Bull 2003;24:5–28.
8. Joint FAO/WHO Expert Consultation. Vitamin and mineral requirements in human nutrition. Geneva: World Health Organization, 2002.
9. Allen LH, Ahluwalia N. Improving iron status through diet. The application of knowledge concerning dietary iron bioavailability in human populations. Washington, DC: John Snow/OMNI Project, 1997.
10. Hallberg L, Hoppe M, Andersson M, Hulthén L. The role of meat to improve the critical iron balance during weaning. Pediatrics 2003;111:864–70.
11. Menon P, Ruel MT, Loechl C, Pelto G. From research to program design: the use of formative research to develop a behavior change communication program to prevent malnutrition in Haiti. Food Consumption and Nutrition Division Discussion Paper. Washington, DC: International Food Policy Research Institute, 2003.
12. Lutter CK. Macrolevel approaches to improve the availability of complementary foods. Food Nutr Bull 2003;24:83–103.
13. Committee on International Nutrition. Vitamin C fortification of food aid commodities: final report. Washington, DC: National Academy Press, 1997.
14. Hurrell R. How to ensure adequate iron absorption from iron-fortified food. Nutr Rev 2002;60:S7–15.
15. Rosado JL. Zinc and copper: proposed fortification levels and recommended zinc compounds. J Nutr 2003;133: 2985S–9S.
16. WHO. Focused ethnographic study of diarrhoeal disease manual. Division for the control of diarrhoeal and respiratory diseases. Geneva: World Health Organization, 1994.
17. Zlotkin S, Antwi KY, Schauer C, Yeung G. Use of microencapsulated iron(II) fumarate sprinkles to prevent recurrence of anaemia in infants and young children at high risk. Bull World Health Organ 2003;81:108–15.
18. Zlotkin S, Arthur P, Schauer C, Antwi KY, Yeung G, Piekarz A. Home-fortification with iron and zinc sprinkles or iron sprinkles alone successfully treats anemia in infants and young children. J Nutr 2003;133: 1075–80.
19. Brown K, Dewey K, Allen L. Complementary feeding of young children in developing countries: a review of current scientific knowledge. Geneva: World Health Organization, 1998.

APPENDIX 1. Nutrient composition of donated commodities per 100 g

Nutrient	WSB	CSB	SBF	Oil
Water (g)	8.8	9.7	8.7	
Energy (kcal)	354.5	375.7	33.9.8	884
Protein (g)	21.5	17.2	18.2	
Total lipids (g)	5.9	6.9	1.3	100
Carbohydrates (g)	46.9	61.7	69.6	
Fiber, total dietary (g)	13.18	9	18.18	
Ash (g)	2.0	1.8	2.2	
Calcium (mg)	842	831	110	
Iron (mg)	17.85	17.49	2.90	0.02
Magnesium (mg)	227.26	173.8	182.90	0.03
Phosphorus (mg)	294	206	356	
Potassium (mg)	694	634	706	
Sodium (mg)	13.8	7.3	17.5	
Zinc (mg)	5.5	5.0	2.0	
Copper (mg)	1.0	0.9	0.9	
Manganese (mg)	2.2	0.7	3	
Selenium (μg)	2.0	6.0	2.0	
Vitamin C (mg)	40	40	0	
Thiamine (mg)	0.54	0.53	0.44	
Riboflavin (mg)	0.50	0.48	0.26	
Niacin (mg)	8.19	6.23	3.53	
Pantothenic acid (mg)	3.7	3.4	1.2	
Vitamin B_6 (mg)	0.47	0.5	0.4	
Folate (μg)	275	300	150	
Vitamin B_{12} (μg)	1	1	0	
Vitamin A (IU)	2,323	2,612	2,205	6,000
Vitamin E (mg)	8.3	8.7	0.1	18.2
Vitamin D (IU)	198	198		
Iodine (μg)	56.88	56.9		

WSB, Wheat-soy blend; CSB, corn-soy blend; SFB, soy-fortified bulgur.
Source: www.usaid.gov/hum_response/crg/fswheatsoyblend.htm. Accessed September 12, 2004.

APPENDIX 2. Estimation of the amounts of beef and beef liver needed to close the iron gap for infants between six and eight months of age who are fed enriched gruels

TABLE A1. Requirements for absorbable iron [7]

Bioavailability	% absorption	Recommended iron intake (mg)	Absorbed iron requirements (mg) = recommended intake * % absorption
High	15%	7.0	1.05
Medium	10%	10.9	1.09
Low	5%	20.8	1.04

TABLE A2. Example of calculations of the amounts of beef that would need to be consumed by children six to eight months old to complement selected gruels fed twice a day in order to fulfill their requirements for iron

Amount of beef required if beef is not eaten at the same meal as gruel					
	Iron content (mg)	Iron absorbed[a] (mg)	Absorbed iron gap (mg)	Additional iron intake needed from beef (mg)	Beef needed to provide extra iron (g)
Gruel	(A)	(B) = (A)* bioavailability	(C) = 1.05–(B)	(D) = (C)/0.25	[(D)/3.33]*100
CSB gruel with dried fish	10.4	0.884	0.166	0.66	19.94
CSB gruel with beans and sugar	9.8	0.588	0.462	1.85	55.50
Wheat flour gruel with beans and dried fish	2.4	0.204	0.846	3.38	101.62
Wheat flour gruel with beans and sugar	2.24	0.1344	0.9156	3.66	109.98
Amount of beef required if 20 g of beef is eaten at the same meal as gruel[b]					
	Iron content (mg)	Gruel iron absorbed with added 20 g of beef (mg)	Absorbed iron provided by beef (mg)[c] (estimated to be 25%)	Absorbed iron gap (mg)	Additional beef needed to close absorbed iron gap (g)
Gruel (g)	(A)	(B) = (A)* bioavailability	(C) = (3.33*0.25)/5	(D) = 1.05-(B+C)	[(D)/(3.33*0.25)] *100
CSB gruel with dried fish	10.4	1.56	0.17	–0.68	–81.26
CSB gruel with beans and sugar	9.8	1.078	0.17	–0.19	–23.36
Wheat flour gruel with beans and dried fish	2.4	0.36	0.17	0.52	62.88
Wheat flour gruel with beans and sugar	2.24	0.2464	0.17	0.64	76.53

a. Assumptions about bioavailability: low (6%) for sweet CSB and wheat flour gruels, low-medium (8.5%) for CSB and wheat flour gruels containing dried fish.

b. Assumptions about *increase* in bioavailability with addition of red meat: Increase from low (6%) to medium (11%) for sweet CSB and wheat flour gruels, and increase from low-medium (8.5%) to high (15%) for CSB and wheat flour gruels containing dried fish [10].

c. Nutrient composition values for beef were obtained from the USDA National Nutrient Database for Standard Reference Release 15 (available at http://www.nal.usda.gov/fnic/foodcomp/Data/SR15/sr15.html). Accessed September 29, 2004.

Feeding of nonbreastfed children from 6 to 24 months of age in developing countries

Kathryn G. Dewey, Roberta J. Cohen, and Nigel C. Rollins

1. Introduction

Although breastfeeding is recommended for two years or more [1], there are circumstances under which this is not possible or desirable. In particular, the current epidemic of HIV/AIDS in parts of the developing world has forced policy makers to evaluate what type of infant-feeding recommendations to make to HIV-positive mothers, who may transmit the virus to their infants via breastmilk. The most recent international guidelines state that "when replacement feeding is acceptable, feasible, affordable, sustainable and safe, avoidance of all breastfeeding by HIV-infected mothers is recommended" [2]. When these conditions cannot be met, it is recommended that mothers breastfeed exclusively for the first few months and stop as soon as alternative feeding options become feasible. Other circumstances that may prevent a child from being breastfed include death or severe illness of the mother, or inability or lack of desire by the mother to breastfeed. Guidelines regarding replacement feeding from birth to six months for infants of HIV-positive mothers have been published elsewhere [2]. After the first six months, however, there is little information on how to construct a nutritionally adequate diet for the nonbreastfed child.

Kathryn Dewey and Roberta Cohen are affiliated with the Program in International Nutrition, University of California, Davis, California, USA. Nigel Rollins is affiliated with the Department of Paediatrics and Child Health, University of Kwa-Zulu-Natal, Durban, South Africa.

Please direct queries to the corresponding author: Kathryn G. Dewey, Department of Nutrition, University of California, One Shields Ave., Davis, CA 95616-8669; e-mail: kgdewey@ucdavis.edu.

This paper was written as the Technical Background Paper for an informal meeting in Geneva (March 8–10, 2004) to discuss feeding of nonbreastfed children 6 to 24 months of age in developing countries, organized by the Department of Child and Adolescent Health and Development and the Department of Nutrition for Health and Development of the World Health Organization.

The age range from 6 to 24 months is a critical period, when malnutrition and infection are particularly common in developing countries. For breastfed children, a set of recommendations in the form of 10 Guiding Principles was recently issued regarding complementary feeding within this age range [3]. Many of these Guiding Principles can also be applied to nonbreastfed children (Nos. 3, 4, 6, and 10). Others, however, need to be revised for nonbreastfed infants.

This document will cover appropriate feeding of nonbreastfed children from 6 to 24 months of age, with a focus on developing-country populations. The Guiding Principles that will be addressed include No. 5 (amount of food needed), No. 7 (meal frequency and energy density), No. 8 (nutrient content of foods), and No. 9 (use of vitamin-mineral supplements or fortified products). To address Nos. 8 and 9, linear programming (LP) techniques were used to develop diets that can meet nutrient requirements within this age range.

2. Use of animal milk for infants between 6 and 12 months of age

The issue of whether to include animal milk in the diet of infants under 12 months of age has been debated for decades. Most of the debate has focused on the use of whole cow's milk. The three main concerns are that cow's milk is low in iron (and the iron is not very well absorbed because milk also contains large amounts of bovine proteins and calcium, which inhibit nonheme iron absorption), can cause occult blood loss from the gastrointestinal tract, and has a high potential renal solute load (PRSL) [4, 5]. In the earlier part of the twentieth century, the use of whole cow's milk during infancy, even during the first four months of life, was common in the United States [5]. By the 1960s, concerns were raised by studies showing that cow's milk could cause occult gastrointestinal blood loss in infants with iron-deficiency anemia. The Committee on Nutrition of the American Academy of Pediatrics (CON-AAP) [6] stated in 1976 and 1983 that for nonbreastfed infants more than six months old, iron-fortified formula was the most convenient source of iron, but cow's milk together with regular use of iron-fortified cereals was acceptable. However, subsequent studies showing that blood loss could occur even in nonanemic infants, along with the recognition that the electrolytic iron in iron-fortified cereals is probably of low bioavailability, prompted the CON-AAP to recommend in 1992 that nonbreastfed infants be given iron-fortified formulas throughout the first year of life.

More recent papers on occult blood loss suggest that in the older infant the losses are very minor and not likely to affect iron status [7, 8]. The gastrointestinal response to cow's milk that causes blood loss decreases with age and disappears by 12 months [8]. Furthermore, there appears to be a dose-response relationship between the quantity of cow's milk and the amount of blood lost, such that only large volumes of milk would pose a significant risk between 6 and 12 months. Heat-treated cow's milk does not provoke blood loss [9], so use of boiled or evaporated milk would eliminate this risk. Thus, the risk of iron deficiency provoked by occult blood loss appears to be low and can be further reduced by heat treatment or restrictions on the amount of milk consumed. Although the low iron content and bioavailability of cow's milk can contribute to anemia, iron deficiency can be avoided by using iron supplements or fortified foods with adequate bioavailability.

The remaining issue is the potential renal solute load (PRSL) of cow's milk, which is considerably higher than that of breastmilk because of the higher content of protein and several minerals (sodium, chloride, potassium, and phosphorus). PRSL refers to the solutes coming from the diet that must be excreted by the kidney if none are used for growth and none are lost through nonrenal routes [4]. A high PRSL can lead to hypernatremic dehydration under conditions of water stress.

The potentially adverse consequences of feeding undiluted cow's milk to young infants have been recognized for more than 100 years [5]. This recognition led to various recipes for formulas that involved the addition of water and carbohydrate to the milk (for example, a typical evaporated milk formula used in the United States in the 1940s consisted of one can (13 ounces) of evaporated milk, 19 fluid ounces of water, and approximately 1 ounce of carbohydrate such as corn syrup) [5]. Over time, commercially prepared infant formulas were developed that came closer to approximating the nutritional composition of human milk, and these have become the standard for nonbreastfed infants in industrialized countries.

During the first six months of life, when infants usually receive nearly all of their nutrients from a single source (breastmilk or formula), it is important to ensure that the PRSL of that product is appropriate. However, when infants begin to consume a mixed diet, the risks of providing a product with a relatively high PRSL, such as undiluted cow's milk, can be avoided if a sufficient amount of fluid is included in the overall diet. The greatest danger from a high PRSL occurs when the child has diarrhea and is losing far more water than usual. Continued use of cow's milk (or other foods with a high PRSL) during diarrhea, without providing extra fluids, can exacerbate the situation. Thus, if cow's milk is a significant part of the diet, special attention needs to be paid to ensuring adequate hydration during illness. In section 3.6, this issue is revisited using information on the PRSL of the diets generated by LP.

3. Using linear programming (LP) to design diets for nonbreastfed children

3.1 LP

LP is a technique that can be used to develop diets that meet nutritional requirements at the lowest possible cost [10–12]. It has been used for decades for feeding domestic animals, but only recently has the technique been applied to human diets. Briefly, LP allows one to minimize any linear function of a set of variables (e.g., cost) while fulfilling numerous constraints (e.g., energy and nutrient requirements, maximum amount of each food that can feasibly be consumed). The solver function in Microsoft Excel can be used to run the program. For a given population, the only information needed is the list of locally available foods and their costs, and the typical amounts of each food consumed by children in the designated age range. In this report, the age ranges used for the LP analyses were 6 to 9, 9 to 12, and 12 to 24 months.

3.2 Methods used in this report

3.2.1 Food-availability scenarios

To develop dietary recommendations that could be applied under a wide range of circumstances, the LP analyses were conducted assuming several different scenarios regarding the availability and affordability of milk products:

» Commercial infant formula available
» Animal milk products available, but not infant formula
» No animal milk products available

Within each of these scenarios, LP runs were conducted both with and without the inclusion of other types of animal-source foods, such as eggs, chicken, meat, chicken liver, and fish. In all runs, iron, zinc, and calcium supplements were allowed to enter the solution if necessary (i.e., if no solution could be found without one or more of those supplements). The costs of these supplements were set artificially high in order to "force" the program to choose foods whenever possible, rather than supplements. In two other sets of runs (sections 3.5.2 and 3.5.3), a fortified, fat-based complementary food supplement (Nutributter) or a fortified corn-soy blend (CSB) flour was allowed to enter the solution. The composition of Nutributter and CSB used in these analyses is shown in table 1. In these runs, the cost of Nutributter was set somewhat high (US$0.10 per 20-g dose) to minimize the amount of Nutributter that was chosen. The cost of CSB was estimated to be US$0.04 per 100 g. In another set of runs (section 3.5.4), three different complementary food supplements—Nutributter; Foodlets, a multiple micronutrient developed by UNICEF; and Sprinkles—were each allowed to enter the solutions one at a time (the composition of each of these products is shown in table 1). In these runs, more realistic cost estimates for these supplements were used (US$0.06 per 20 g of Nutributter; US$0.03 per dose of Foodlets or Sprinkles) [13] so that an overall cost comparison of the resulting diets, and of the diets with CSB, could be made (it should be noted, however, that these three complementary food supplements are still undergoing research testing and are not yet widely available, and CSB is generally available only through food aid programs). Finally, in another set of runs (section 3.5.5), heat-treated expressed breastmilk was substituted for cow's milk to determine the nutritional feasibility of this option for HIV-positive mothers.

3.2.2 Datasets used to develop food lists and maximum amounts consumed

Datasets on the dietary intake of children between 6 and 15 months of age were available from five countries: Bangladesh [15], Ghana [16], Guatemala [17], Honduras [18], and Peru [19] (see details in table 2). The information from the latter three countries was combined to represent the Latin America region.

These datasets were used to determine the foods consumed most often by infants in that population and the maximum amount of each food ever consumed by any child in each of the countries. This information was used to develop the food lists to be used in the LP runs. To maximize the possibility of developing nutritionally adequate diets using local foods, nutrient-dense foods such as meat, chicken liver, and eggs were added to the food lists, even if they were only rarely consumed by a given population. Table 3 shows the food lists for each of the three regions represented. In general, the maximum amount of each food that was allowed to enter the LP solution was set at 90% of the maximum amount ever consumed by any child in any of the five countries. However, for some foods the maximum amount ever consumed was very low (< 20 g), so in these cases the maximum for the LP runs was set at 20 g. For eggs, the maximum was set at 50 g (one egg), given that it would not be feasible to recommend more than one egg per day in most circumstances.

Information on the costs of local foods in each country was also obtained (table 3). The LP runs were set up to minimize the total cost of each diet, using this cost information.

3.2.3 Food-composition data and bioavailability assumptions

Food-composition data were taken from the International Minilist [20] whenever possible. This database includes information on phytate content, which was used for estimating zinc bioavailability. When a given food was not available in the International Minilist, data were obtained from US Department of Agriculture (USDA) food-composition tables or the World Food Program [20]. For Ghana, the nutrient content of various recipes typically used for infant feeding was calculated using the USDA food-composition data.

The LP runs were structured to take into account the estimated bioavailability of iron, zinc, and calcium from the foods in each diet. The absorption of iron was assumed to be 6% from plant-source foods, 11% from animal-source foods (including milk, in which the bioavailability of iron is lower than in meats), and 8.5% from iron supplements. Zinc absorption was estimated based on the phytate-to-zinc ratio of the diet, using a nonlinear regression to smooth out the step function published by the Food and Agriculture Organization/World Health Organization/International Atomic Energy Agency (FAO/WHO/IAEA) [21]. The absorption of calcium was assumed to be 25% for legumes, roots or tubers, and grains, 5% for foods with high oxalate content (e.g., spinach), 45% for other fruits and vegetables, 32% for all other foods (including dairy products), and 30% for calcium supplements [22].

3.2.4 Constraints on nutrient intake

In each LP run, the solution had to meet several constraints regarding nutrient intake. First, the total energy content of the diet had to be equal to the energy requirements for each age range (615 kcal/day for 6–9 months, 686 kcal/day for 9–12 months, and 894 kcal/day for 12–24 months) [23]. Second, the fat content of the diet had to provide at least 30% of the energy. Third, each solution had to meet or exceed the recommended nutrient intake (RNI) for protein and nine selected micronutrients (vitamin A, thiamine, riboflavin, vitamin B_6, folate, vitamin C, calcium, iron, and zinc). These nine nutrients were selected because they were identified as potential "problem nutrients" for children 6 to 24 months of age [23]. Niacin was also identified as a potential problem nutrient, but it was not included as a constraint in the LP runs because of the difficulty of estimating the amount of niacin available via the conversion from tryptophan.

The RNI values chosen for this analysis were based on the latest WHO/FAO or Institute of Medicine (IOM) Dietary Reference Intakes recommendations

TABLE 1. Composition of complementary food supplements and corn-soy blend

Nutrient	Nutributter[a] (per 20 g)	Foodlets (per one dose)[b]	Sprinkles (per one dose)[c]	CSB[d] (per 100 g)
Energy (kcal)	108	0	0	376
Protein (g)	2.5	0	0	17.2
Fat (g)	7	0	0	6.9
Vitamin A (μg RE)	400	375	300	784
Thiamine (mg)	0.3	0.5	0	0.5
Riboflavin (mg)	0.4	0.5	0	0.5
Niacin (mg)	4	6	0	6
Vitamin B_6 (mg)	0.3	0.5	0	0.5
Vitamin B_{12} (μg)	0.5	0.9	0	1.0
Folic acid (μg)	80	150	150	300
Pantothenic acid (mg)	1.8	0	0	3.4
Vitamin C (mg)	30	35	50	40
Vitamin D (μg)	0	5	7.5	5
Vitamin E (mg)	0.4	6	0	8.7
Calcium (mg)	100	0	0	831
Copper (mg)	0.2	0.6	0	n/a
Iodine (μg)	90	50	0	57
Iron (mg)	9	10	12.5	17.5
Magnesium (mg)	16	0	0	174
Manganese (mg)	0.08	0	0	n/a
Phosphorus (mg)	82	0	0	206
Potassium (mg)	152	0	0	n/a
Selenium (μg)	10	0	0	n/a
Zinc (mg)	4	10	5	5
Phytate (mg)	83	0	0	877

RE, Retinol equivalent; n/a, not available.

a. Nutributter is a fortified, fat-based spread produced by Nutriset (Malauney, France). The composition shown here is for a version used in a trial on complementary feeding in Ghana, 2003-04. The ingredients include vegetable fat, peanut paste, dry skimmed milk powder, dry whey, maltodextrin, sugar, and vitamin/mineral complex.

b. As shown in Nestel et al. [13].

c. Current formulation (S. Zlotkin, personal communication).

d. Corn-soy blend [14].

TABLE 2. Studies from which dietary data were available for the linear programming runs

Country	Age range (mo)	*N*	No. of records/ child	Total no. of records	Dietary data collection
Bangladesh [15]	6–12	126	1	126	Weighed intake (by observer)
Ghana [16]	6–12	190	1–5	501	Weighed intake (by observer)
Guatemala [17]	6–15	305	1–6	1,552	Weighed intake (by observer)
Honduras [18]	6–9	127	1–6	706	Maternal recall
Peru [19]	6–12	127	1–6	739	Weighed intake (by observer)

[23], whichever was lower for a given nutrient (for the 6- to 12-month age interval). The lower value was chosen because most of the RNI values are based on "adequate intake" estimates, which may overestimate actual nutrient needs. Choosing the lower values also maximized the chance of finding a solution that met nutrient needs using local foods. To estimate the recommended amount of *absorbed* iron, zinc, and calcium, the relevant RNIs were multiplied by 0.1, 0.33, and 0.3, respectively (the bioavailability factors used in calculating the RNIs). Thus, the amounts of these nutrients to be provided by the LP solutions at 6 to 12 months were 0.93 mg of absorbed iron, 1.0 mg of absorbed zinc, and 81 mg of absorbed calcium. At 12 to 24 months, the respective amounts were 0.58, 1.0, and 150 mg.

TABLE 3. Foods included for each region, 90% of maximum amount consumed in grams in each region (90% max.), and costs used in linear programming runs

No.	Latin America	90% max.	$US/ 100 g	Bangladesh	90% max.	$US/ 100 g	Ghana	90% max.	$US/ 100 g
1.	Banana, raw, ripe	115	0.05	Banana (ripe)	115	0.03			
2.	Beef, medium fat	40	0.58				Beef, thin, roasted	40	0.19
3.	Bread, wheat, white	75	0.03	Bread	75	0.48	Bread, wheat, white	75	0.17
4.	Cassava root, white boiled	185	0.14				Cassava root, white boiled	185	0.09
5.	Chicken, mature, meat	95	0.59	Chicken	95	0.73	Chicken, mature, meat	95	0.65
6.	Crackers, salty or savory	20	0.48	Crackers	20	0.05			
7.	Egg, chicken, raw or cooked	50	0.20	Egg	50	0.10	Egg, chicken, raw or cooked	50	0.34
8.	Halibut, cooked, dry heat	75	0.37	Fish	75	0.22	Fish, smoked tuna	75	0.18
9.	Infant formula, lactogen, dry	140	3.00	Infant formula, dry	140	3.00	Infant formula, lactogen, dry	140	3.00
10.	Kidney bean, mature boiled	80	0.03	Lentil-cooked (dal)	80	0.05	Soybean, mature boiled	20	0.04
11.	Liver, chicken	35	0.59	Liver, chicken	35	0.83	Liver, chicken	35	0.18
12.	Mango, ripe, raw	80	0.03	Mango	80	0.17			
13.	Milk (cow), whole, not fortified	1,000	0.05	Milk (cow)	1,000	0.05	Milk (cow), whole, not fortified	1,000	0.05
14.				Onion	20	0.03	Onion, bulb, raw or boiled	20	0.06
15.	Orange, raw	180	0.07	Orange juice	180	0.11	Orange juice	180	0.03
16.	Papaya, ripe, raw	155	0.11	Papaya	155	0.13	Papaya, ripe, raw	155	0.12
17.	Pasta, wheat, white, cooked	70	0.03	Vermicelli	70	0.10			
18.	Peas, green, boiled	20	0.08				Cowpea, mature boiled	80	0.04
19.	Plantain, cooked	180	0.05				Plantain, cooked	180	0.05
20.	Potato, baked or boiled	125	0.07	Potato	125	0.02			
21.	Rice, white, unenriched, cooked	195	0.02	Rice (cooked)	195	0.03	Rice, white, unenriched, cooked	195	0.06
22.	Soybean oil	35	0.37	Oil	35	0.07	Palm oil, red, fresh	35	0.12
23.	Spinach, boiled	40	0.13	Spinach	40	0.02	Leaf, taro	40	0.06
24.	Squash, winter, yellow, cooked	130	0.09	Pumpkin	130	0.03			
25.	Sweet potato, tuber, orange	80	0.11				Yam, white, tuber, cooked	60	0.10
26.	Tomato, ripe or green	65	0.30				Tomato, ripe or green	65	0.06
27.	Tortilla, maize, lime-treated	75	0.07	Ruti (wheat tortilla)	75	0.03			
	Region-specific foods								
28.	Apple, raw	65	0.27				Banku	295	0.03
29.	Avocado	30	0.14				Corn dough	130	0.03
30.	Cabbage, boiled	55	0.07	Coconut (dry)	20	0.04	Fish, fresh mackerel	75	0.15
31.	Cantaloupe, raw	80	0.05	Guava	25	0.05	Groundnut soup	100	0.03

continued

TABLE 3. Foods included for each region, 90% of maximum amount consumed in grams in each region (90% max.), and costs used in linear programming runs *(continued)*

No.	Latin America	90% max.	$US/ 100 g	Bangladesh	90% max.	$US/ 100 g	Ghana	90% max.	$US/ 100 g
32.	Carrots, raw or boiled	85	0.08	Gur (cane sugar, brown)	20	0.03	Kenkey	100	0.03
33.	Cheese, hard, whole milk	20	0.35	Semolina	20	0.05	Kontomire stew	125	0.04
34.	Oats, rolled or meal, cooked	270	0.04				Koose	140	0.07
35.	Pineapple, raw	60	0.10				Okra soup (fresh or dried)	180	0.03
36.	Shortening, hydrogenated vegetable	35	0.10				Palm soup	160	0.03
37.	Squash, summer, cooked (fruit)	70	0.09				Sugar, white	45	0.03
38.							Tomato stew	100	0.03
39.							TZ (corn and millet porridge)	405	0.04

3.3 Results of initial LP runs with no limits on food choices

The initial set of LP runs was conducted without any limits on the number or types of different foods that could be included in a solution, focusing first on the age range from six to nine months. This was done for each of the three regions represented, and for each scenario described in section 3.2.1 (six combinations: formula + other animal-source food; formula but no other animal-source food; milk + other animal-source food; milk but no other animal-source food; no milk, but other animal-source food available; and no milk or other animal-source food). Micronutrient supplements were allowed, but these runs did not include Nutributter as an option. In Latin America and Bangladesh, solutions that did not include micronutrient supplements were possible only when formula was included. In Ghana, it was possible to get a solution that did not include micronutrient supplements if both milk and other animal-source foods were included. However, the solution had three different types of animal-source foods (besides milk): chicken liver, beef, and fish. This diet and most of the other diets that resulted from these initial LP runs were considered impractical because they generally incorporated multiple types of animal-source foods and a large number of different types of fruits and vegetables to be consumed all on the same day. In addition, many of these solutions included trivial amounts (< 5 g) of some foods, and did not include any of the staple foods for the region (e.g., no rice was included in the solutions for Bangladesh). Therefore, the programs were rerun after imposing additional constraints on the food choices.

3.4 Additional constraints on food choices

To achieve solutions that were more practical for translating into daily dietary recommendations, the following additional constraints were imposed:

Other than egg, only one other nonmilk animal-source food (meat, chicken, fish, or chicken liver) at a time was allowed. Thus, for solutions that included nonmilk animal-source foods, there were five options: egg only, egg + beef, egg + chicken, egg + fish, and egg + chicken liver. These five options were run both with and without the inclusion of infant formula or milk products. All resulting combinations were also run both with and without the inclusion of Nutributter.

The number of different fruits and vegetables allowed in a solution was restricted to two types of fruit and three types of vegetables at a time. These runs used the following choices: For Latin America, banana, papaya, spinach, avocado, and carrot in the first set of runs; in later runs, melon, mango, cabbage, and winter squash were substituted one at a time for banana, papaya, spinach, and carrot, respectively. For Bangladesh, guava, papaya, spinach, and pumpkin in the first set of runs; in later runs, banana was substituted for guava and mango was substituted for papaya. For Ghana, papaya, orange juice, tomato, taro leaf, onion, and okra soup.

If a solution included less than 5 g of any individual food, that food was deleted and the LP analysis was rerun. The only exception was oil, in which case the minimum was set to 5 g any time oil entered the solution.

The minimum amount of staple food was set at 30 g. The staple food was defined as rice (or rice products) in Bangladesh, TZ (a maize and millet porridge) in Ghana, and tortilla (or maize products) in Latin

America. In later runs in Latin America, bread or rice was substituted for tortilla as the "staple food" (i.e., a minimum of 30 g was imposed).

For options in which animal milk was included, the minimum amount of milk was set at 200 g.

Sugar was deleted as a food choice in all regions. Coconut was deleted as a food choice in Bangladesh (because its fibrous consistency may be inappropriate for infants), and oatmeal was deleted in Latin America (because oats are usually imported).

3.5 Results of LP runs with limits on food choices

3.5.1 Without complementary food supplements or fortified corn-soy blend (CSB)

When infant formula was allowed into the solution at 6 to 9 months and 9 to 12 months, the amount that entered ranged from 279 to 486 ml/day when other animal-source foods were included (except when chicken liver was part of the diet, when the amount of formula that entered decreased to 100 to 186 ml/day). When no other animal-source foods were included, the amount of formula selected was 407 to 543 ml/day.

When no infant formula was allowed into the solution, the results varied greatly, depending on the other foods in the diet. Tables 4 to 12 show the amounts of foods in each solution for six different scenarios: (1) dairy products (whole cow's milk, and in Latin America, cheese) + egg + one other animal-source food; (2) dairy products + egg but no other animal-source food; (3) dairy products but no other animal-source food; (4) no animal-source food; (5) no animal-source food, but Nutributter included; and (6) no animal-source food, but CSB included. Each table represents a different region and one of the three age intervals. The first column shows the foods permitted to enter the solution, and the second column shows the maximum quantity that was allowed to enter (in grams of cooked food except for CSB, which is shown as the dry amount). The remaining six columns show the amounts of each food that entered the solution for each of the six scenarios above. This section will discuss the first four scenarios.

At six to nine months (tables 4–6), no solution was possible without the inclusion of an iron supplement. The amount of supplemental iron required ranged from 1.2 to 7.8 mg/day, depending on the amount and type of animal-source foods in the diet. When there was no animal-source food in the diet (scenario 4), supplemental calcium (19–113 mg/day) and zinc (0.6–1.5 mg/day) were also needed. The amount of supplemental calcium required depended on the region and the type of staple food chosen for Latin America (less calcium was required when tortillas were included, because the maize is treated with lime). When other animal-source foods were in the diet (scenarios 1 and 2), the amount of milk in the solution was approximately 200 ml/day (the imposed minimum) in Bangladesh, 200 to 345 ml/day in Ghana (the higher amount was needed for scenario 2), and 200 to 369 ml/day in Latin America (less milk was required when bread was the staple than when tortillas or rice were the staple). When no other animal-source foods were in the diet (scenario 3), the amount of milk in the solution was 340 ml/day in Bangladesh, 490 ml/day in Ghana, and 399 to 496 ml/day in Latin America. When egg was allowed (scenarios 1 and 2), the amount that entered was the maximum (50 g), except in Ghana when beef was included. The amount of meat, chicken, fish, or chicken liver in scenario 1 ranged from 30 to 75 g/day. For beef, fish, and chicken liver, the amount that entered the solution was generally the maximum allowed (40, 75, and 35 g/day, respectively). Grain products were "forced" into all solutions at a minimum of 30 g/day, but the amount that entered varied depending on the other foods in the diet. Legumes entered all solutions. Up to seven additional foods entered the solutions, usually including one fruit and one to three vegetables. Oil was added to almost all diets in Bangladesh but was required only for scenario 4 (no animal-source food) in Latin America and Ghana.

At 9 to 12 months (tables 7–9), the situation was similar. No solution was possible without the inclusion of an iron supplement. The amount of supplemental iron required ranged from 0.7 mg/day (in Ghana, scenario 1 with chicken liver) to approximately 5 to 7 mg/day (scenarios 2–4). When there was no animal-source food in the diet, supplemental calcium (5–117 mg/day) and zinc (0.7–1.5 mg/day) were also needed (except in Bangladesh, where no solution for scenario 4 was possible unless the maximum amount of spinach allowed was increased to 100 g; in this situation no supplemental zinc was needed). When other animal-source foods were in the diet, the amount of milk in the solution was approximately 200 ml/day in Bangladesh, 200 to 337 ml/day in Ghana, and 200 to 365 ml/day in Latin America. When no other animal-source foods were in the diet (scenario 3), the amount of milk in the solution was 339 ml/day in Bangladesh, 483 ml/day in Ghana, and 375 to 516 ml/day in Latin America. When egg was allowed, the maximum amount (50 g) always entered (except in Ghana when beef was included). The amount of meat, chicken, fish, or chicken liver in scenario 1 ranged from 28 to 75 g/day. Legumes entered all solutions. Oil was added to almost all diets in Bangladesh and Ghana, but was required only for scenario 4 (no animal-source food) in Latin America.

At 12 to 24 months (tables 10–12), iron supplements were not required in Ghana but were required for scenarios 2 to 4 in Latin America and all scenarios in Bangladesh except when chicken liver was included. The amount of supplemental iron required in those two regions was approximately 1 to 3 mg/day, considerably less than at 6 to 12 months. When there was no animal-source food in the diet, supplemental calcium (210–330 mg/day) and zinc (0.3–1.3 mg/day) were also needed. In Bangladesh, no solution for scenario 4 (no animal-source food) was possible unless the maximum amount of spinach was increased to 120 g. In Ghana, nonmilk animal-source foods did not enter the solutions (except when chicken liver was the option), but the amount of milk included in scenarios 1 to 3 was 339 to 351 ml/day. In Latin America and Bangladesh, the amount of milk in the solution was 200 to 352 ml/day when other animal-source foods were in the diet and 376 to 439 ml/day when no other animal-source foods were allowed. When egg was allowed, none entered in Ghana, but the maximum amount (50 g) entered in Latin America and Bangladesh except when chicken liver was included. The amount of meat, chicken, fish, or chicken liver in scenario 1 for Latin America and Bangladesh ranged from 20 to 75 g/day. Legumes entered all solutions. Oil was required for most scenarios in Bangladesh and for certain diets in scenarios

TABLE 4. Solutions for Latin America, 6–9 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200–236	249–369	399–496	—	—	—
Cheese	20	0 (MPL) 20 (F)	20	20	—	—	—
Egg	50	50	50		—	—	—
M, P, F, L							
Beef	40	40	—	—	—	—	—
Chicken	95	or 51–69	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Tortilla	75	0–61	0–30	0–30	75	75	30
Bread	75	0–30	0–31	0–30	0–30	41	14
Rice	195	0–30	0–31	0–30	0–30	0	0
Crackers	20	0	0	0	0–18	0	0
Pasta	70	0	0	0	0	0	0
Legumes							
Red beans	80	55–80	68–80	64–80	0–39	80	80
Roots/tubers/ plantain/cassava							
Plantain	180	0–24	0	0	0–6	0	0
Sweet potato	80	0–34	0	0	80	0	0
Cassava	185	0	0	0	0	0	0
Potato	0	0	0	0	0	0	0
Spinach	40	40	40	40	40	0	40
Other vegetables							
Avocado	30	0–26	29–30	0–18	30	0	30
Carrot	85	85	85	85	85	83	76
Fruits							
Papaya	155	14 –35	0–32	28–30	155	0	0
Banana	115	0	0	0	0	0	0
Oil	35	0	0	0	12–13	10	11
Fe supplement (mg)		2.2–5.8	6.3–6.4	7.0–7.1	7.3–7.8	0	0
Ca supplement (mg)		0	0	0	9–28	0	0
Zn supplement (mg)		0	0	0	1.3–1.5	0	0.5
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

M, meat; P, poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; tortilla, rice, or bread—30 g (only one of these three foods was forced per run). Food limits: fruits—only banana and papaya; vegetables—only spinach, carrots, and avocado.

1, 3, and 4 in Latin America.

In Ghana, the solutions included three different types of legumes (groundnuts, soybeans, and cowpeas), whereas there was only one source of legumes in the diets for Latin America and Bangladesh. This may explain why nonmilk animal-source foods generally did not enter the solutions at 12 to 24 months in Ghana. With fewer types of legumes available, nonmilk animal-source foods would be needed at this age in Ghana.

One important consideration in the above LP analyses is the conversion factor used to estimate the amount of vitamin A obtainable from β-carotene in plant foods. The food-composition tables use a ratio of 6:1 for the conversion of β-carotene to retinol equivalents (RE), but recent data indicate that a ratio of 12:1 is more appropriate [24]. Thus, if all of the vitamin A in the LP solutions came from plant sources, the actual amount of usable vitamin A would be approximately half of the amount estimated by the program. This was not a concern for the LP solutions for Latin America or Bangladesh, because all of them (even those with no animal-source foods) included more than 800 RE of vitamin A (twice the RNI of 400 RE), and thus would have been adequate even if a ratio of 12:1 had been used. For Ghana, most of the LP solutions had less than

TABLE 5. Solutions for Bangladesh, 6–9 months

Food type	Max. grams per day	Dairy + egg + P, F, or L[a]	Dairy + egg	Dairy, no egg or P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200	204	340	—	—	—
Egg	50	50	50	—	—	—	—
P, F, L							
Chicken	95	34	—	—	—	—	—
Fish	75	or 73	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Bread	75	0	0	0	0	0	16
Rice	195	30	30	30	30	30	30
Crackers	20	0	6	0	20	20	0
Semolina	20	0	0	0	0	0	0
Pasta	70	0	0	5	0	0	0
Legumes							
Lentils	80	80	80	80	80	80	80
Roots/tubers/ plantain/cassava							
Potato	125	72–125	125	125	100	64	0
Spinach	40	40	40	40	100[b]	40	40
Other vegetables							
Pumpkin	130	130	130	130	130	130	130
Onion	20	0	20	20	20	20	20
Fruits							
Papaya	155	0	0	0	155	155	0
Guava	25	0	25	25	25	25	25
Oil	35	0–5	5	6	17	10	15
Fe supplement (mg)		2.5–5.7	6.2	6.9	5.6	0	0
Ca supplement (mg)		0	0	0	113	28	0
Zn supplement (mg)		0	0	0	0.6	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; rice—30 g. Food limits: fruits—only guava and papaya; vegetables—only spinach, pumpkin, and onions.

a. Meat was not included because it was never consumed by young children in the study population.

b. Riboflavin limiting, no solution possible unless spinach maximum is increased.

800 RE of vitamin A. To evaluate actual vitamin A adequacy, the Ghana analyses were rerun after multiplying the vitamin A content of the plant source foods by 0.5. All of the solutions yielded identical diets to those shown in tables 10 to 12 and had more than 400 RE of vitamin A (adjusted). Thus, the diets in tables 4 to 12 are adequate in vitamin A even if a 12:1 conversion ratio for β-carotene is utilized.

Another important consideration in these analyses is the maximum amount of nonmilk animal-source foods allowed in scenarios 1 and 2. To optimize the ability to meet nutrient needs from local foods, the maximum amounts chosen (90% of the maximum amount consumed in any of the sites) were relatively high (40 g of beef, 75 g of fish, 95 g of chicken, 35 g of chicken liver, and 50 g of egg). Most infants in devel-

TABLE 6. Solutions for Ghana, 6–9 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200	345	490	—	—	—
Egg	50	0 (M) 50 (PFL)	50	—	—	—	—
M, P, F, L							
Beef	40	40	—	—	—	—	—
Chicken	95	or 30	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Bread	75	0	0	0	0	0	0
Rice	195	0	0	0	0	0	0
TZ	405	59–129	94	87	32	30	30
Corn dough	130	0	0	0	0	0	20
Banku /kenkey	295	0	0	0	0	0	0
Legumes							
Cowpeas	80	80	80	80	80	80	80
Groundnut soup	100	0–39	0	0	100	100	100
Soybeans	20	20	20	20	20	20	20
Roots/tubers/ plantain/cassava							
Cassava	185	0	0	0	0	20	0
Yam	60	0	7	0	0	0	0
Plantain	180	0	0	0	0	0	0
Taro leaf	40	40	40	40	40	40	22
Other vegetables							
Onion	20	0	0	0	20	20	0
Okra soup	180	0–21	0	0	180	20	47
Fruits							
Papaya	155	0	0	0	155	155	0
Orange juice	180	0	0	0	180	180	0
Tomato	65	65	65	65	65	0	0
Oil	35	0–5	0	0	5	0	1
Fe supplement (mg)		1.2–4.7	5.1	5.8	5.9	0	0
Ca supplement (mg)		0	0	0	39	0	0
Zn supplement (mg)		0	0	0	0.8	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

M, Meat; P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; TZ (corn and millet porridge)—30 g. Food limits: fruits—only orange juice, papaya, and tomato; vegetables—taro leaf, onion, and okra soup.

oping countries do not consume these quantities of animal-source foods. Among children under two years of age in the United States who consume these foods, the mean consumption of red meat (35 g), eggs (46 g), and organ meats (66 g) is similar to or greater than the maximum amounts allowed in the LP analyses, but the mean consumption of poultry (45 g) and fish (40 g) is considerably lower than the maximum allowed [25]. Thus, the diets for scenarios 1 and 2 may be unrealistic and might lead to an underestimation of the amount of milk needed if consumption of animal-source foods is less than the amounts that entered each solution. To evaluate this possibility, the LP analyses for these two scenarios were rerun using maximum amounts for nonegg animal-source foods set at the 75th percentile of consumption (for the site with the highest consumption of that food). These maximums were 14 g of beef, 38 g of fish, 20 g of chicken, and 21 g of chicken

TABLE 7. Solutions for Latin America, 9–12 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200–300	200–365	375–516	—	—	—
Cheese	20	0 (MPL)14–20 (F)	20	20	—	—	—
Egg	50	50	50	—	—	—	—
M, P, F, L							
Beef	40	40	—	—	—	—	—
Chicken	95	or 48–78	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Tortilla	75	0–71	0–30	0–52	75	75	30
Bread	75	0–30	0–30	0–30	0–30	63	39
Rice	195	0–30	0–30	0–30	0–30	0	0
Crackers	20	0	0	0–20	0–20	0	0
Pasta	70	0	0	0	0	0	0
Legumes							
Red beans	80	77–80	80	80	29–80	80	80
Roots/tubers/ plantain/cassava							
Plantain	180	0–90	0–49	0–64	0	0	0
Sweet potato	80	0–31	0–56	0–52	59–80	0	0
Cassava	185	0–7	0	0	0	0	0
Potato	0	0	0	0	0	0	0
Spinach	40	4 0	40	40	40	0	40
Other vegetables							
Avocado	30	0–3	30	0–30	30	0	30
Carrot	85	85	85	85	85	79	55
Fruits							
Papaya	155	16–35	0–23	0–12	155	0	0
Banana	115	0	0	0	0	0	0
Oil	35	0–5	0	0	13–15	12	12
Fe supplement (mg)		2.2–5.5	5.9–6.0	6.6–6.7	6.5–7.4	0	0
Ca supplement (mg)		0	0	0	5–18	0	0
Zn supplement (mg)		0	0	0	1.4–1.5	0	0.5
Nutributter	20	—	—	—	—	20	—
CSB	60						60

M, meat; P, poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; tortilla, rice, or bread—30 g (only one of these three foods was forced per run). Food limits: fruits—only banana and papaya; vegetables—only spinach, carrots, and avocado.

liver. The maximum for eggs was kept at 50 g because that amount is equivalent to approximately one egg. In these reanalyses, the amount of milk that entered remained approximately the same in Bangladesh, but there were changes in the amounts of some of the non-animal-source foods and a slight increase in the amount of iron supplement required. For Ghana, there was also very little change in the amount of milk that entered, but the amount of iron supplement required increased slightly. For Latin America, there was a small increase in the amount of milk (a difference of 0–81 ml, depending on which animal-source food was allowed), but the amount did not exceed 350 ml in any of the solutions; the amount of iron supplement required also increased slightly. The full amount of egg allowed (50 g) entered most of the solutions, so it could still be argued that these diets contain more animal-source foods than is realistic for developing countries. For this reason, scenarios 3 to 6 in tables 4 to 12 may be more appropriate in most circumstances.

3.5.2 With Nutributter

The LP runs that included Nutributter (at US$0.10 per 20 g) were done both with and without imposing the additional constraints described in section 3.4. Infant formula did not enter any of the solutions at any age.

TABLE 8. Solutions for Bangladesh, 9–12 months

Food type	Max. grams	Dairy + egg + P, F, or L[a]	Dairy + egg	Dairy, no egg or P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200	203	339	—	—	—
Egg	50	50	50	—	—	—	—
P, F, L							
Chicken	95	44	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Bread	75	0	5	0	75	0	9
Rice	195	30	30	30	30	30	30
Crackers	20	0–12	20	18	20	20	0
Semolina	20	0–9	0	0	0	0	0
Pasta	70	0–9	0	0	0	0	53
Legumes							
Lentils	80	80	80	80	39	80	80
Roots/tubers/ plantain/cassava							
Potato	125	121–125	125	125	6	122	0
Spinach	40	40	40	40	100[b]	40	40
Other vegetables							
Pumpkin	130	130	130	130	130	130	130
Onion	20	0–12	20	20	20	20	20
Fruits							
Papaya	155	0	0	0	155	155	0
Guava	25	25	25	25	25	25	25
Oil	35	0–6	5	6	17	12	17
Fe supplement (mg)		2.3–5.4	6.1	6.7	6.5	0	0
Ca supplement (mg)		0	0	0	117	25	0
Zn supplement (mg)		0	0	0	0	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; rice—30 g. Food limits: fruits—only guava and papaya; vegetables—only spinach, pumpkin, and onions.

a. Meat was not included because it was never consumed by young children in the study population.

At 6–9 and 9–12 months, the amount of Nutributter that entered was close to the maximum allowed (19–20 mg/day). At 12 to 24 months, only 9 to 10 mg of Nutributter entered when milk products were allowed. When milk was allowed but no minimum amount was set, the amount of milk included in the solutions for Ghana was 121 ml at 6–9 and 9–12 months, and 343 ml at 12–24 months. For Latin America, the amount of milk included was 0 ml at 6–9 months, 36 ml at 9–12 months, and 259 ml at 12–24 months. For Bangladesh, the amount of milk included was 108 ml at 6–9 months, 111 ml at 9–12 months, and 335 ml at 12–24 months. Other animal-source foods did not enter the solutions when Nutributter was included (except for 7 g of cheese in Latin America at 6–9 months).

The second-to-last column of tables 4 to 12 shows

TABLE 9. Solutions for Ghana, 9–12 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200	337	483	—	—	—
Egg	50	12–50	50	—	—	—	—
M, P, F, L							
Beef	40	40	—	—	—	—	—
Chicken	95	or 28	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 35	—	—	—	—	—
Grains							
Bread	75	0	0	0	0	0	0
Rice	195	0	0	0	0	0	0
TZ	405	94–161	115	107	30	30	30
Corn dough	130	0	0	0	0	44	56
Banku /kenkey	295	0	0	0	0	0	0
Legumes							
Cowpeas	80	80	80	80	80	80	75
Groundnut soup	100	0–52	0	40	100	100	96
Soybeans	20	20	20	20	20	20	20
Roots/tubers/ plantain/cassava							
Cassava	185	0	0	0	57	0	0
Yam	60	0–19	7	0	0	0	0
Plantain	180	0	0	0	0	0	0
Taro leaf	40	40	40	0	40	40	0
Other vegetables							
Onion	20	0	0	0	20	14	0
Okra soup	180	0–21	0	0	180	180	0
Fruits							
Papaya	155	0	0	0	155	0	0
Orange juice	180	0	0	0	180	180	0
Tomato	65	65	65	65	65	0	0
Oil	35	0–5	5	5	5	0	6
Fe supplement (mg)		0.7–4.5	4.9	5.6	5.6	0	0
Ca supplement (mg)		0	0	0	30	0	0
Zn supplement (mg)		0	0	0	0.7	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

M, Meat; P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; TZ (corn and millet porridge)—30 g. Food limits: fruits—only orange juice, papaya, and tomato; vegetables—taro leaf, onion, and okra soup.

the solutions when Nutributter was included in a diet with no animal-source foods, applying the constraints described in section 3.4. At all ages, solutions were obtained without the need for additional iron or zinc supplements. Because the formulation of Nutributter used in these analyses included only a modest amount of calcium (100 mg per 20 g), in some situations the solution included additional calcium. At 6–9 and 9–12 months, this was necessary only in Bangladesh, where a small amount (25–28 mg) of additional calcium was included in the solution. At 12 to 24 months, it was necessary in all sites (115–249 mg of additional calcium), because the RNI for calcium at that age is much higher than at 6 to 12 months (500 vs. 270 mg).

The diets shown in the second-to-last column of tables 4 to 12 generally contain one or two types of grain products, legumes, occasionally tubers, one to three vegetables, zero to three fruits, and usually some additional oil. It should be noted that the maximum amount of Nutributter allowed (20 g) is a modest

TABLE 10. Solutions for Latin America, 12–24 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	200–230	277–312	423–439	—	—	—
Cheese	20	0–20 (all)	0–20	15–20	—	—	—
Egg	50	0 (L) 50 (MPF)	50		—	—	—
M, P, F, L							
Beef	40	40	—	—	—	—	—
Chicken	95	or 76–88	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 24–25	—	—	—	—	—
Grains							
Tortilla	75	5–75	0–30	0–33	75	75	30
Bread	75	0–75	0–30	0–30	0–30	0	75
Rice	195	0–30	0–30	0–30	0–30	0	0
Crackers	20	0	0	0	20	20	0
Pasta	70	0–70	0–40	0–70	0	0	70
Legumes							
Red beans	80	80	80	80	80	80	0
Roots/tubers/ plantain/cassava							
Plantain	180	0–180	178–180	130–180	0	0	0
Sweet potato	80	0	0	0	80	80	0
Cassava	185	0–114	0	0	16–64	0	0
Potato	0	0	0	0	0	0	0
Spinach	40	40	40	40	40	40	40
Other vegetables							
Avocado	30	0–30	30	30	30	30	0
Carrot	85	0– 85	85	85	85	83	31
Fruits							
Papaya	155	0–34	0	0	155	155	0
Banana	115	0	0	0	0–45	0	90
Oil	35	0–11	0	0–5	19–20	13	22
Fe supplement (mg)		0–0.5	1.0–1.1	1.7–2.0	1.8–2.0	0	0
Ca supplement (mg)		0	0	0	210–216	115	0
Zn supplement (mg)		0	0	0	1.3	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

M, meat; P, poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; tortilla, rice, or bread—30 g (only one of these three foods was forced per run). Food limits: fruits—only banana and papaya; vegetables—only spinach, carrots, and avocado.

amount and could be increased, especially in the second year of life. In addition, the amount of calcium included in the product could be increased. This has the potential to simplify the diets further.

3.5.3 With CSB

The LP runs with CSB allowed for a maximum of 60 g of this product, a typical ration size in feeding programs for infants and young children. The additional constraints described in section 3.4 were also imposed. In all sites, at all ages, the maximum amount of CSB entered the solutions. When milk was allowed, no more than the minimum amount of 200 ml of milk entered. When other animal-source foods were allowed, egg entered most of the solutions in Bangladesh (8–38 g) and Latin America (10–50 g), but not in Ghana. Other animal-source foods rarely entered in Bangladesh or Ghana, but cheese, fish, or chicken liver sometimes entered in Latin America. The last column of tables 4 to 12 shows the solutions when no animal-source food was allowed. In Latin America, these were generally similar to the solutions using Nutributter, except

TABLE 11. Solutions for Bangladesh, 12–24 months

Food type	Max. grams	Dairy + egg + P, F, or L[a]	Dairy + egg	Dairy, no egg or P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	273–352	310	376	—	—	—
Egg	50	22(L) 50 (P,F)	50	—	—	—	—
P, F, L							
Chicken	95	46	—	—	—	—	—
Fish	75	or 75	—	—	—	—	—
Liver (chicken)	35	or 20	—	—	—	—	—
Grains							
Bread	75	0–69	41	67	55	44	0
Rice	195	30	30	30	30	30	78
Crackers	20	20	20	20	20	20	20
Semolina	20	0–20	20	15	0	0	0
Pasta	70	0	0	0	70	70	0
Legumes							
Lentils	80	80	80	80	80	80	80
Roots/tubers/ plantain/cassava							
Potato	125	125	125	125	125	125	125
Spinach	40	40	40	40	120[b]	40	40
Other vegetables							
Pumpkin	130	0–130	130	130	130	130	130
Onion	20	0–20	20	20	20	20	20
Fruits							
Papaya	155	0–20	0	0	155	155	0
Guava	25	0–25	25	25	25	25	19
Orange juice	180	—	—	—	—	—	0
Banana	115	—	—	—	—	—	0
Oil	35	0–5	5	5	21	14	21
Fe supplement (mg)		0–0.9	1.6	2.2	0.5	0	0
Ca supplement (mg)		0	0	0	330	249	0
Zn supplement (mg)		0	0	0	0.3	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; rice—30 g. Food limits: fruits—only guava and papaya; vegetables—only spinach, pumpkin, and onions.

a. Meat was not included because it was never consumed by young children in the study population.

b. Riboflavin limiting, no solution possible unless spinach maximum is increased.

that the CSB substituted for some of the other grain products (and legumes at 12–24 months), spinach and avocado were added, and the CSB diets at 6–9 and 9–12 months required the addition of 0.5 mg of zinc. In Bangladesh, the solutions using CSB required fewer foods than the solutions using Nutributter (e.g., potato was deleted at 6–9 and 9–12 months, and papaya was deleted at all ages), but were otherwise similar. In Ghana, the solutions using CSB required less taro leaf, onion, okra soup, and orange juice than the solutions using Nutributter.

3.5.4 Cost comparisons with three different complementary food supplements and CSB

Nutributter is not the only product that could be added to home-produced foods to boost the nutritional

TABLE 12. Solutions for Ghana, 12–24 months

Food type	Max. grams per day	Dairy + egg + M, P, F, or L	Dairy + egg	Dairy, no egg or M, P, F, or L	No ASF	No ASF; Nutributter added	No ASF; CSB added
Milk	1,000	339–351	339	339	—	—	—
Egg	50	0	0	—	—	—	—
M, P, F, L							
Beef	40	0	—	—	—	—	—
Chicken	95	0	—	—	—	—	—
Fish	75	0	—	—	—	—	—
Liver (chicken)	35	or 14	—	—	—	—	—
Grains							
Bread	75	0	0	0	0	0	0
Rice	195	0	0	0	0	0	0
TZ	405	67–185	185	185	157	30	30
Corn dough	130	53–130	53	53	0	0	130
Banku/kenkey	295	0	0	0	0	0	0
Legumes							
Cowpeas	80	80	80	80	80	80	0
Groundnut soup	100	92–100	92	92	100	100	100
Soybeans	20	20	20	20	20	20	20
Roots/tubers/ plantain/cassava							
Cassava	185	0	0	0	48	135	0
Yam	60	0	0	0	0	0	0
Plantain	180	0	0	0	0	0	0
Taro leaf	40	0–40	40	40	40	40	6
Other vegetables							
Onion	20	0	0	0	20	20	0
Okra soup	180	0	0	0	180	180	105
Fruits							
Papaya	155	0	0	0	155	155	0
Orange juice	180	15–34	15	15	180	180	0
Tomato	65	0	0	0	65	65	0
Oil	35	0	0	0	7	5	17
Fe supplement (mg)		0	0	0	0	0	0
Ca supplement (mg)		0	0	0	251	147	0
Zn supplement (mg)		0	0	0	0.5	0	0
Nutributter	20	—	—	—	—	20	—
CSB	60	—	—	—	—	—	60

M, Meat; P, Poultry; F, fish; L, liver (chicken); ASF, animal-source foods; CSB, corn-soy blend. Amounts shown are per gram of cooked food, except for CSB, which is the dry amount. Food minimums: milk—200 g; TZ (corn and millet porridge)—30 g. Food limits: fruits—only orange juice, papaya, and tomato; vegetables—taro leaf, onion, and okra soup.

content of diets for infants and young children. Other options include crushable micronutrient tablets (called “Foodlets” by UNICEF) and Sprinkles, both of which can be mixed with foods for infants [13]. To compare these options, the LP runs were conducted with these three complementary food supplements allowed one at a time, using the cost estimates described in section 3.2.1. Table 13 summarizes the food costs for these diets and for the CSB diets in Latin America, Bangladesh, and Ghana using two scenarios: including milk (minimum of 200 ml/day) but no other animal-source food, and without any animal-source food. In the latter scenario, calcium and zinc supplements were allowed to enter the solution if needed, but the cost of these additional nutrients was not included.

When milk was included, the total cost of the diet was similar across the four options (Nutributter, Sprinkles, Foodlets, or CSB) at 6–9 and 9–12 months in Bangladesh and Ghana, ranging from US$0.18 to 0.24 per day, whereas in Latin America, the CSB option was more costly (US$0.31–0.33) than the other three options (US$0.24–0.26) at these ages. When no animal-source food was allowed, the total cost of the diet at 6–9 and 9–12 months was lowest with the Nutributter option in Latin America (US$0.26–0.27 vs. US$0.27–0.65 for the other options), but in the other two sites it was lowest with the CSB option (US$0.14–0.24 vs. US$0.30–0.54 for the other options). At 12 to 24 months, the CSB option was less expensive (US$0.17–0.29) than the other three options (US$0.29–0.83) in all sites, regardless of whether milk was included. It should be noted that in Bangladesh, no solution could be reached for the “no animal-source food” scenario with the Sprinkles or Foodlets options unless the maximum amount of spinach allowed was increased to 100 g (this was not the case for the Nutributter or CSB options). It should also be kept in mind that the costs shown in table 13 are rough estimates and could vary greatly depending on changes in local food costs. The choice of which option is most appropriate in a given situation will depend not only on cost, but also on availability and acceptability.

3.5.5 LP runs with heat-treated expressed breastmilk

For HIV-positive mothers, one option is to express their breastmilk, use heat treatment to inactivate HIV, and feed the treated milk to their infants. This may be a more practical option after six months, when milk is no longer the sole source of nutrients, than during the first six months, when sustained expression of sufficient quantities of milk may be difficult. Expressed breastmilk is a readily available, less costly option than commercial infant formula or cow’s milk. To evaluate the types of foods that would be needed to complement expressed breastmilk, the LP runs for 6–9 and 9–12 months were repeated with heat-treated breastmilk as an option instead of cow’s milk. The nutrient composition of human milk may be altered by heat treatment, but preliminary data suggest that the changes are minor except for vitamin C concentration, which appears to be reduced by about 20% [26]. Thus, for these LP runs, the composition of the human milk was assumed to be similar to that of milk from well-nourished women [27], but with the concentration of vitamin C reduced by 20%. The cost of human milk was set at US$0.01 per 100 ml, to allow for fuel costs for heat treatment (by comparison, the cost of cow’s milk was US$0.05 per 100 ml). The amount of expressed breastmilk allowed into the LP solution was constrained by using a minimum of 200 ml/day and a maximum of 400 ml/day.

The results of these LP runs were similar to those using cow’s milk, although different foods were sometimes chosen and the amounts varied somewhat. The amount of supplemental iron required was somewhat higher with breastmilk than with cow’s milk, due to the lower iron content of human milk (0.3 mg/L, compared with 1.0 mg/L for cow’s milk). Similarly, for scenarios that included little or no other animal-source food, some of the solutions included a small amount of zinc or calcium supplement when breastmilk was used but not when cow’s milk was used. This is because the zinc and calcium concentrations in human milk are lower than those in cow’s milk (zinc 0.9 vs. 4.0 mg/L, and calcium 280 vs. 1,150 mg/L, respectively). The amount of breastmilk that entered was approximately 200 ml in Latin America, 300 to 400 in Bangladesh, and 200 to 300 in Ghana. In Latin America less breastmilk than cow’s milk entered the solutions for the scenarios that included no other animal-source food or egg as the only other animal-source food, whereas in Bangladesh more breastmilk than cow’s milk was used for most options. In Ghana, the amount of breastmilk that entered varied depending on the dietary scenario.

Thus, a nutritionally adequate diet can be designed using heat-treated expressed breastmilk and appropriate complementary foods plus an additional source of iron (as is true for diets that include cow’s milk). Although these LP runs do not demonstrate an advantage of breastmilk over cow’s milk at this age with regard to the 12 nutrients considered in these analyses, they do not take into account all of the nutritional differences that may have functional consequences (e.g., certain fatty acids), nor the non-nutritive benefits of human milk (e.g., anti-infective properties, although there is little information on whether, or the extent to which, breastmilk from an HIV-infected woman protects her child from other infections) [28]. The cost of the overall diet is likely to be considerably lower if expressed breastmilk is used in place of cow’s milk, and if no animal milk is available at all, the inclusion of expressed breastmilk is likely to significantly enhance dietary quality.

TABLE 13. Cost comparisons of diets including Nutributter, Sprinkles, Foodlets or corn-soy blend (US$)

Location	Nutributter	Sprinkles	Foodlets	Corn-soy blend
6–9 mo				
With milk				
Latin America	0.25	0.24	0.24	0.31
Bangladesh	0.24	0.20	0.18	0.21
Ghana	0.23	0.21	0.21	0.20
Without milk				
Latin America	0.26	0.65	0.65	0.27
Bangladesh	0.40	0.40	0.38	0.22
Ghana	0.47	0.49	0.49	0.14
9–12 mo				
With milk				
Latin America	0.26	0.26	0.25	0.33
Bangladesh	0.22	0.21	0.19	0.21
Ghana	0.23	0.22	0.22	0.21
Without milk				
Latin America	0.27	0.65	0.65	0.49
Bangladesh	0.41	0.42	0.42	0.24
Ghana	0.30	0.54	0.54	0.12
12–24 mo				
With milk				
Latin America	0.32	0.40	0.37	0.25
Bangladesh	0.29	0.33	0.33	0.19
Ghana	0.30	0.34	0.33	0.21
Without milk				
Latin America	0.79	0.82	0.83	0.29
Bangladesh	0.49	0.54	0.50	0.19
Ghana	0.64	0.62	0.60	0.17

3.6 Evaluation of potential renal solute load (PRSL) and extra fluid needed

The diets resulting from each of the LP solutions described in sections 3.5.1 and 3.5.2 were evaluated further for their PRSL and water content. PRSL was calculated using the following equation [4]:

$$\text{PRSL} = \text{Na} + \text{Cl} + \text{K} + \text{P} + (\text{protein} / 175)$$

(PRSL in milliosmoles; Na, Cl, K, and P in millimoles; protein in milligrams)

Because the Cl content of most foods is not listed in food-composition tables, Cl was estimated by multiplying the Na content by 1.5.

Across all age groups and sites, PRSL ranged from a low of 124 mOsm to a high of 461 mOsm, and was generally higher for diets that included nonmilk animal-source food. By making certain assumptions about urine concentration and the amount of nonrenal water loss expected, these PRSL values can be used to estimate the amount of water required from the total diet. These calculations are based on the following equation [4]:

$$C_{\text{urine}} = \text{RSL}_{\text{est}} / [W_f - W_e]$$

where C_{urine} is urinary concentration (mOsm/L), RSL_{est} is renal solute load (mOsm/day), W_f is water intake (L/day), and W_e is extrarenal water loss (L/day). RSL is generally less than PRSL because of the use of solutes for growth. To be conservative, PRSL was substituted for RSL in the above equation when solving for W_f. This results in the following equation:

$$W_f = [\text{PRSL}/C_{\text{urine}}] + W_e$$

The renal concentrating ability (C_{urine}) of an infant at about nine months of age is estimated to be 1,100 mOsm/L [4], but to allow for a margin of safety a value of 700 mOsm/L was used. Thus, the first part of the above equation [$\text{PRSL}/C_{\text{urine}}$] would range from 0.18 to 0.66 L/day (180–660 ml/day) for the range of PRSL values observed. W_e can be calculated based on assumed body weight. Under normal climatic conditions, W_e is about 60 ml/kg/day [4]. Based on estimated body weights of 7.5 kg at 6 months, 8.5 kg at 9 months, 9.75 kg at 12 months, and 12.3 kg at 24 months, W_e would be 480 ml/day at 6–9 months, 548 ml/day at 9–12 months, and 662 ml/day at 12–24 months.

Using the above equation, table 14 shows the estimated total water needs of nonbreastfed children in each age interval, based on either a low- or a high-PRSL diet. Under normal climatic conditions, total water needs are 690 to 900 ml/day with a low-PRSL diet and 1,010 to 1,210 ml/day with a high-PRSL diet. The amount of fluid coming from the diet can be subtracted from the total amount of water needed (based on each diet's PRSL) to estimate the amount of extra fluids required in each dietary scenario. The water content of these diets was 220 to 560 ml/day for the low-PRSL diets and 510 to 740 ml/day for the high-PRSL diets. The estimated net amount of extra water needed is 470 to 500 ml/day at 6–9 months, 450 to 530 ml/day at 9–12 months, and 340 to 470 ml/day at 12–24 months. This fluid can be provided as plain water or other beverages, or it can be used to make a porridge from the rice and/or other foods in the solution.

Under hot conditions, extrarenal water losses increase. If we assume that they are doubled under tropical conditions, the above equation can be applied using a value for W_e of 960 ml/day at 6–9 months, 1,096 ml/day at 9–12 months, and 1,324 ml/day at 12–24 months. This results in an estimate of the extra fluid to be incorporated into the diet of 950 to 980 ml/day at 6–9 months, 990 to 1,080 ml/day at 9–12 months, and 1,000 to 1,130 ml/day at 12–24 months (table 14).

Extrarenal water losses during diarrhea can be two to three times greater than normal, with the resulting total water need being increased accordingly. Fever can also increase extrarenal water losses. In such circumstances, it is essential that extra fluids be provided in addition to the water that would be coming from the normal diet. If the infant refuses the quantity of water needed, it may be necessary to restrict the intake of foods that are high in PRSL during illness. The foods with the highest PRSL in these sites were fish, cheese, chicken, beef, and chicken liver.

3.7 Evaluation of protein quality

Although the LP analyses were set up to ensure that the total amount of protein in each solution was adequate, they did not include individual amino acid requirements. This is partly because of uncertainty about amino acid requirements during infancy and early childhood [29]. For the diets in tables 4 to 12 that included animal-source foods (scenarios 1–3), the total amount of protein ranged from 24 to 52 g/day (14%–30% of energy), which is approximately two to five times the amount needed. Given that these diets included animal protein and that the total amount of protein was generous, there is very little risk of inadequate intake of individual amino acids.

The diets that could be more problematic are those without animal-source foods (scenarios 4–6 in tables 4–12). The total amount of protein in these diets ranged from 14 to 26 g/day. All of these diets included both grains and legumes, which enhances protein quality. Nonetheless, it is possible that some of them would provide less than the desired amounts of certain essential amino acids. Inspection of these diets suggested that the potentially limiting amino acids are lysine, sulfur-containing amino acids (methionine + cysteine), and tryptophan. To evaluate amino acid adequacy, the total amounts of these amino acids provided by each of the diets lacking animal-source foods were calculated and compared with recommended amino acid intakes for each age interval [30]. The results indicated that all of the diets were adequate in these amino acids, with one exception: the "no animal-source food" (without Nutributter) option for Latin America at six to nine months, which was short in lysine (630 mg/day, with tortillas as the staple grain, compared with the recommended amount of approximately 676 mg/day). This diet was also the lowest in total protein (14 g/day), with all other diets containing at least 17 g/day. Thus, nearly all of the options presented in tables 4 to 12 have adequate protein quality.

TABLE 14. Estimated water needs of nonbreastfed children (ml/day)

		Normal climate			Hot climate		
Age (mo)	PRSL[a]	Total water needed	Amount from foods	Extra water needed	Total water needed	Amount from foods	Extra water needed
6–9	Low[b]	690	220	470	1,170	220	950
	High[c]	1,010	510	500	1,490	510	980
9–12	Low[b]	760	310	450	1,300	310	990
	High[c]	1,080	550	530	1,630	550	1,080
12–24	Low[b]	900	560	340	1,560	560	1,000
	High[c]	1,210	740	470	1,870	740	1,130

a. PRSL, Potential renal solute load.
b. Based on the average of the lowest PRSL observed in each site at this age.
c. Based on the average of the highest PRSL observed in each site at this age.

4. Meal frequency and energy density

The number of feedings required depends on the overall energy density of the diet. Theoretical estimates of required meal frequency and energy density can be calculated from the total amount of energy required, assuming a gastric capacity of 30 g/kg body weight/day [23]. To meet the needs of nearly all children, 2 SD is added to the average age-specific total daily energy requirements. Table 15 shows the minimum number of meals required with three different estimates of energy density (0.6, 0.8, and 1.0 kcal/g). At the lowest energy density (0.6 kcal/g), five or six meals per day would be needed. This decreases to approximately four meals per day when energy density is at least 0.8 kcal/g, and to approximately three meals per day when energy density is at least 1.0 kcal/g. If a child typically consumes amounts that are less than the assumed gastric capacity at each meal, meal frequency would need to be higher than the values in table 15.

Conversely, the minimum dietary energy density required depends on meal frequency. Table 15 shows that the minimum energy density is about 0.65 kcal/g when there are five meals per day, 0.75 kcal/g when there are four meals per day, and 1.0 kcal/g when there are three meals per day.

These estimates provide a margin of safety because 2 SD has been added to the average energy requirement. Thus, not all children will need the number of meals shown in table 15. Since it is not possible to know which children have higher or lower energy requirements, caregivers should be attentive to the child's hunger cues when judging how often and how much to feed the child.

5. Review of experience with feeding nonbreastfed children

5.1 Replacement feeding of infants of HIV-positive mothers

Recent experience with replacement feeding of infants of HIV-positive mothers has reinforced concerns about the risks associated with bottle feeding of animal milks or infant formulas in developing countries. For example, in a study of 148 infants of HIV-positive mothers in India [31], the hospitalization rate during the follow-up period from birth to about 13 weeks was 0 among breastfed infants vs. 0.093 per 100 person-days in the replacement-fed infants ($p < .0001$). Four infants died, all of whom were replacement fed. In that setting, replacement feeding usually consisted of "top feeding," which is done with animal milk (cow, goat, or buffalo) diluted with water. Provision of ready-to-feed infant formula and instructions in its use could certainly reduce the risk of contamination and associated morbidity and mortality. However, in most situations contamination of milk fed by bottle is widespread. In periurban Peru, for example, 35% of bottle nipples tested positive for *Escherichia coli* [32], and in a semiurban slum in India, 54% of milk samples were contaminated by bacteria [33].

Aside from the issue of contamination, there has been concern about the nutritional adequacy of replacement diets. In formative research in Zambia to develop recommendations on replacement feeding, it was found that diets for infants over six months of age were nutritionally inadequate, even with breastmilk included, and that removing breastmilk would worsen the situation (E. Piwoz, personal communication).

Although some clinical and operational research

TABLE 15. Energy requirements, minimum meal frequency, and minimum dietary energy density for nonbreastfed children 6–24 months of age

Requirement	6–9 mo	9–12 mo	12–24 mo
Average energy requirement (kcal/day)	615	686	894
Energy requirement + 2 SD (+ 25%)	769	858	1,118
Functional gastric capacity (g/meal), based on 30 g/kg body weight	249	285	345
Number of meals required for given energy density			
0.6 kcal/g	5.1	5.0	5.4
0.8 kcal/g	3.9	3.8	4.1
1.0 kcal/g	3.1	3.0	3.2
Minimum energy density (kcal/g) required for given daily meal frequency			
3/day	1.03	1.00	1.08
4/day	0.77	0.75	0.81
5/day	0.62	0.60	0.65

studies have described the difficulties associated with implementing replacement feeding, few have reported on the micronutrient status of infants and young children in these studies or the association between nutritional status and the type of replacement feeding adopted. Nor is there clarity regarding the provision of micronutrient supplements to children in programs for the prevention of postnatal mother-to-child transmission of HIV infection (PMTCT).

To gather information on these issues, 10 research groups that are either involved with clinical PMTCT studies or are supporting operational programs in some capacity in eight countries in sub-Saharan Africa (Botswana, Côte d'Ivoire, Kenya, Malawi, South Africa, Uganda, Zambia, and Zimbabwe), were asked four questions regarding their study or program protocols:

» What replacement milk or food is recommended as an initial alternative to breastfeeding or after breastfeeding stops (especially after six months of age), and what support is offered?
» Are micronutrients offered to any children in the PMTCT study or program, and if so, what criteria are used to indicate that a child should receive supplements?
» What is the composition of the supplement, and how was this supplement chosen?
» What are the study or program recommendations regarding iron supplements for HIV-exposed infants, and what protocols are used for managing anemia?

The information obtained from those who responded (see Acknowledgments) is summarized below.

5.1.1 Replacement milk or food recommended and support offered

Research groups in Botswana, Côte d'Ivoire, Kenya, South Africa, and Zambia recommended and provided commercial infant formula as a breastmilk substitute for infants up to 12 months; some groups also provided bottles and teats or cups and also pots for sterilizing bottles. The national PMTCT programs in Botswana and South Africa provide infant formula to HIV-infected women for 12 and 6 months, respectively. In South Africa, a mother can avail herself of this supply any time in the child's first year of life, so that she may consider a period of exclusive breastfeeding and then use commercial infant formula to facilitate the transition from breastfeeding. In contrast to the national PMTCT programs, research groups in Côte d'Ivoire, Kenya, and Zambia provide free infant formula for varying periods. In Zambia, mothers participating in a study specifically designed to investigate the feasibility and the nutritional and morbidity consequences of early and abrupt cessation of breastfeeding are given infant formula along with a locally developed, nutrient-enriched cereal blend for three months to provide a nutritious diet when infants are weaned from breastmilk around four months of age.

In Malawi, Uganda, and Zimbabwe, research groups generally followed the national PMTCT protocols, which advocated exclusive breastfeeding unless the mother is able to purchase commercial infant formula herself and has the additional resources to safely prepare and store milk. After the infant is six months of age, full-cream unmodified cow's and goat's milk are also recommended. In Malawi, mothers participating in the research study are provided with the equivalent of 75 g/day of a locally produced, nutrient-fortified, ready-to-use food for infants made from peanuts, powdered milk, cooking oil, sugar, and a micronutrient premix.

Specific counseling on infant-feeding practices, including appropriate complementary feeding, is provided by all groups and programs. The quality, focus, and intensity of this counseling vary greatly, however, depending on the resources available.

5.1.2 Use of micronutrient supplements in PMTCT programs

National PMTCT protocols in each of the countries recommend vitamin A supplements every six months to all infants as part of the Integrated Management of Childhood Illness (IMCI) program. The South Africa PMTCT program also provides a multivitamin supplement containing vitamin A (900 µg), vitamin C (30 mg), vitamin B_1 (1.65 mg), vitamin B_2 (1.32 mg), vitamin B_6 (1 mg), niacin (11 mg), and vitamin D (300 IU/5 ml) to all HIV-exposed infants. The rationale for this was that infected infants would probably benefit, although there was no evidence base for this recommendation and there are no explicit recommendations regarding nonbreastfed infants, especially after six months of age. In a research program in Botswana to study the effect of an antiretroviral regimen given to breastfed infants, a comparable multivitamin preparation (vitamin A 2,330 IU, vitamin D 200 IU, thiamine 1 mg, riboflavin 1.2 mg, pyridoxine 0.5 mg, nicotinamide 5 mg, vitamin C 35 mg, and vitamin B_{12} 2.5 µg/5 ml) is recommended for all breastfed infants to avoid nutritionally related hematological abnormalities that might otherwise be attributed to the antiretroviral regimen.

In a research program in Malawi also investigating the effect of an antiretroviral regimen for HIV-infected mothers and/or their infants, a nutrient-rich, ready-to-use food is provided to infants who are rapidly weaned. The daily quantity of this food is designed to provide vitamin A (683 µg), vitamin C (40 mg), vitamin B_1 (0.5 mg), vitamin B_2 (1.4 mg), vitamin B_6 (0.5 mg), vitamin B_{12} (1.4 µg), folic acid (158 µg), pantothenic acid (2.3 mg), and niacin (4.0 mg), as well as Ca (240 mg), P (296 mg), K (833 mg), Mg (69 mg), Zn (10.5 mg), Cu (1.3 mg), and Fe (8.6 mg). For most nutrients, this formulation was based on replacing the nutrients that breastmilk would otherwise provide to infants 6 to 12 months of age. The product was already available in Malawi and had been formulated as part of the protocol for the treatment of children with severe malnutrition. It had been found to be well tolerated and safe in this setting.

In Zimbabwe, the PMTCT protocol advocates providing "multivitamins" to nonbreastfed infants receiving modified animal milk. However, these are not generally available, and locally manufactured, commercially available multivitamin preparations contain only vitamin A (2,000 IU), vitamin B_1 (1 mg), vitamin B_2 (1 mg), vitamin C (30 mg), and nicotinamide (7 mg/5 ml). Externally supported programs provide the same preparation to infants found to have growth faltering. In the Zambia Exclusive Breastfeeding study, micronutrients are provided via commercial infant formula and by a nutrient-enriched cereal blend containing vitamin A, vitamin E, vitamin C, vitamin D, vitamin B_1, vitamin B_2, vitamin B_3, vitamin B_6, folate, vitamin B_{12}, zinc sulfate, ferrous fumarate, magnesium, and iodine. This was developed by the Zambian National Institute for Scientific and Industrial Research in collaboration with the US Department of Agriculture as a complete replacement diet and is made from locally available foods. It is reportedly highly acceptable to mothers and is easy to prepare. No other supplements are provided in the national PMTCT program.

5.1.3 Use of iron supplements for HIV-exposed infants and management of anemia

None of the PMTCT protocols had an explicit recommendation for iron supplementation before or after the age of six months, regardless of whether the child had been breastfed, abruptly changed from breastmilk to another replacement feed, or replacement fed from birth; each deferred to national protocols or made no comment at all. In the Malawi research project, hemoglobin is tested at all follow-up visits, and adverse events are graded according to age (< 3, 3, or > 3 months) and severity. Iron supplements are not routinely given, since the ready-to-use food (RTUF) is fortified with iron.

National protocols generally recommended oral iron (6 mg of elemental iron/kg/day) with or without folate or multivitamins for treating mild to moderate clinical anemia, preferably with biochemical evidence of iron deficiency; transfusion is generally recommended if hemoglobin drops below 60 g/L. In Zimbabwe, preterm or low-birthweight infants are supposed to receive vitamin D and folate for three months from birth, and iron supplements from one to three months of age. Other countries reported using IMCI guidelines, which include dietary recommendations to improve iron intake and prevention of malaria; prophylactic iron supplementation is recommended in Uganda, though implementation is not always effective.

5.1.4 Need for consistent guidelines and further research

Respondents to the above questions were uniformly interested in learning about the approach of other groups. The WHO technical group on HIV and Nutrition highlighted the need to identify the daily requirements and safe limits for micronutrients in HIV-infected adults and children [34]. Even if a child is not infected with HIV, the likelihood of micronutrient deficiencies during this age period is high. Thus, there is a need for consistent guidelines regarding the types and amounts of fortified products or supplements that are recommended for nonbreastfed children. Research on products that are safe to use in developing-country settings is particularly important. For example, a South African food that may be useful in feeding nonbreastfed infants is a fermented cow's milk product that does not require refrigeration. Although milk products are generally low in iron, it may be possible to fortify such a product for use as a lower-cost, potentially safer alternative to commercial infant formula.

5.2 Adaptation of products used for malnourished children

Although there are published guidelines and formula recipes (e.g., F100 for feeding children with serious infections or severe malnutrition [35]), these are not directly applicable to nonbreastfed children in general. This is because the energy and protein needs of recovering severely malnourished children are much higher than normal, and those who are recovering from serious infections need special diets to minimize adverse reactions such as diarrhea induced by temporary lactose intolerance. Furthermore, the formulas recommended, such as F100, are not as useful for home-based feeding in contaminated environments because they provide an excellent growth medium for pathogenic bacteria.

An earlier version of the Nutributter product described herein (called ready-to-use food, RTUF) was originally developed as an alternative to the F100 formula for rehabilitation of severely malnourished children (after the initial phase of treatment). The advantages of RTUF are that it is resistant to bacterial contamination because it contains no water, can be eaten directly by the child without the addition of water, and has a very high energy and nutrient density. In a recent randomized trial comparing the efficacy of RTUF with that of the F100 formula fed to malnourished children 6 to 36 months of age in a clinical setting in Senegal, the RTUF group had significantly greater daily energy intake and weight gain and a shorter duration of rehabilitation than the F100 group [36]. This demonstrated that a product such as Nutributter can be successfully used to promote weight gain. The RTUF product is now being used for malnourished children in Malawi, and as mentioned above, the same program recently began trying it for children of HIV-positive mothers in the community, because infant formula is considered too risky. So far, there have been no major logistical or acceptability problems in using it, even for children younger than 12 months. A peanut-free version is now ready for field testing (André Briend, personal communication).

In the above trials, a relatively large amount of RTUF was fed, and it was consumed directly from the sachet rather than being mixed with other foods. For severely malnourished children who require very high energy intake, this may be the best strategy, but for nonbreastfed children in general, it would be less expensive to use a small amount of the product as a supplement (either eaten alone or mixed with other foods). The LP runs described in section 3.5.2 indicate that 20 g of Nutributter is generally sufficient in a diet that does not contain animal-source foods, as long as other nutritious foods, such as fruits and vegetables, are available. When the types of foods are even more limited, a larger quantity of Nutributter can be used to satisfy nutrient needs.

The total fluid needs of children fed RTUF or Nutributter should be kept in mind, since the product does not contain water. Fluid needs can be partially satisfied by including animal milks (with due attention to hygiene), but they can also be met by providing plain boiled water or preparing porridges or soups from the foods listed in the diets shown in tables 4 to 12.

6. Conclusions and limitations

The literature reviewed and the results of the LP runs described above suggest the following conclusions:

1. Animal milk, such as undiluted whole cow's milk, can be fed to infants after six months of age, provided that iron supplements or iron-fortified foods with adequate bioavailability are consumed and the amount of fluid in the overall diet is adequate (see section 3.6). Animal milk, such as cow's milk, is a good source of several key nutrients. When the diet does not include fortified foods or supplements, the amounts of milk needed daily range from less than 200 to approximately 370 ml if other animal-source foods are included in the diet, and from approximately 300 to 500 ml if they are not. Raw milk (i.e., not boiled or pasteurized) should be avoided because of the risk of disease transmission. Fermented milk products (e.g., yogurt) hold promise for reducing the risk of illness due to contamination, since they are more resistant to bacterial growth and can be fed more easily by spoon or cup rather than by bottle, as compared with nonfermented liquid milk. Commercial infant formula is an option when it is available and affordable, can be safely used, and provides a nutritional or other advantage over animal milk (e.g., when fortified food products or supplements are not available or are more expensive). In these circumstances, the daily amount of formula needed at 6 to 12 months of age is approximately 280 to 500 ml if other animal-source foods are included in the diet and approximately 400 to 550 ml if they are not.

2. To meet nutrient needs, animal-source foods other than milk are also needed unless multiple micronutrient supplements or fortified products are provided. The daily amounts included in the LP analyses were 50 g of egg (one egg) and 14 to 75 g of meat, poultry, fish, or chicken liver.

3. Iron supplements or fortified products are needed in nearly all situations, in daily amounts ranging from 1 to 8 mg Fe, depending on the age range and other foods in the diet. If animal-source foods are not available, supplements of zinc (0.3–1.5 mg/day) and calcium (5–117 g/day at 6–12 months, 210–330 g/day at 12–24 months) are also needed.

4. Grain products, legumes, fruits, and vegetables should also be included in the diet. If milk and other animal-source foods are not consumed in adequate amounts, both grains and legumes should be consumed daily, if possible within the same meal, to ensure adequate protein quality. In general, one or two types of fruit and one to three types of vegetables per day can be recommended. The amounts included in the LP analyses can be found in tables 4 to 12. These are meant to be examples of the types and amounts of foods to include, not explicit dietary guidelines. Such guidelines need to be created at the local level, based on the types of foods available in the area and at different seasons of the year.

5. If fortified products such as Nutributter, Sprinkles, Foodlets, or CSB are available, there is no need for commercial infant formula, and nonmilk animal-source foods are optional. With adequate levels of micronutrients in the product, there is also no need for additional supplements. If milk is included in the diet, the amount needed is generally less than when fortified products are not included. If milk is not included in the diet, calcium needs may not be completely met (because some of the products contain little or no calcium), and the product would need to contain vitamin B_{12} if there are no other animal-source foods in the diet. Fortified products allow for a simpler and presumably more affordable diet, depending on local food composition and costs.

6. Cost comparisons of three different complementary food supplements (Nutributter, Foodlets, and Sprinkles) and CSB indicate that at 6 to 12 months, the Nutributter or CSB options resulted in lower-cost diets in some situations, but otherwise the costs were similar. At 12 to 24 months, the CSB option was least

expensive. Because it is difficult to incorporate all of the essential micronutrients into Foodlets or Sprinkles, the diets using those options sometimes required a wider variety or larger quantities of fruits and vegetables than the diets based on the Nutributter or CSB options. Nonetheless, the choice of which type of product to use will depend on local circumstances. There is limited experience with the use of complementary food supplements in community settings, but preliminary evidence indicates that they are acceptable to mothers and infants.

7. If animal-source foods are not consumed regularly, 10 to 20 g of added fats or oils are needed unless a fat-rich food is given (such as foods or pastes made from groundnuts, other nuts, and seeds). If animal-source foods are consumed, up to 5 g of additional fats or oils may be needed in some circumstances. Good sources of essential fatty acids (e.g., fish, avocado, nut pastes, and most vegetable oils) should be included.

8. Nonbreastfed infants need at least 400 to 600 ml/day of water (in addition to water contained in foods, including milk) in a temperate climate, and 800 to 1200 ml/day in a hot climate. This water can be incorporated into porridges or other foods, but plain, clean (boiled, if necessary) water is less prone to contamination and should be offered several times per day to ensure that the infant's thirst is satisfied.

9. The number of meals required by nonbreastfed children depends on the energy density of the local foods and the usual amounts consumed at each feed. When the energy density is at least 0.8 kcal/g and children are fed to satiety, four or five meals per day are needed (meals include milk-only feeds, other foods, and combinations of milk feeds and other foods). If the energy density or the amount of food per meal is low, more frequent meals may be required. In all situations, responsive feeding practices that are sensitive to the child's hunger and satiety cues are advisable [3].

It is important to keep in mind that there are several limitations to the LP analyses described here.

First, the analyses are based on meeting the needs for selected nutrients (energy, fat, protein, vitamin A, thiamine, riboflavin, vitamin B_6, folate, vitamin C, calcium, iron, and zinc), not for all of the essential nutrients. Although these are the nutrients considered to be most limiting at this age, the results could be different if other micronutrients were included, such as vitamin E, iodine, phosphorus, selenium, or essential fatty acids. Unfortunately, there is inadequate or unreliable information on the content of these nutrients in many foods, precluding their inclusion in the LP analyses.

Second, there is still uncertainty about the RNI values during infancy, as explained in section 3.2.4, so the results could differ if better estimates were available.

Third, the food-composition data used are subject to error, and there is considerable variability in nutrient content due to local conditions, such as soil, cultivar, processing, etc.

Fourth, although the LP analyses take the bioavailability of iron, zinc, and calcium into account, the calculations are based on the entire day's diet, not the bioavailability of the food in each individual meal. This introduces some unavoidable error into the results.

Fifth, the maximum amounts of individual foods allowed in these analyses were based on a limited number of dietary studies, mostly of breastfed infants under 12 months of age. There was little information on the quantities that could be consumed in the second year of life. As a result, the solutions for children from 12 to 24 months may have been overly constrained by the limitations imposed on food quantity.

Finally, the food cost estimates used in specific LP analyses could be incorrect, and will certainly vary by region and across time. Use of different food costs can greatly alter the types and amounts of foods that appear in the LP solutions.

Several of the above limitations can be overcome by running the LP analyses using locally available data specific to the region of interest. It is important to note that tables 4 to 12 in this report are intended to be an overall guide, not recommendations to be applied to all settings. If local food composition and cost information is available, local authorities can conduct their own assessment of dietary needs for nonbreastfed children in their area. This may yield solutions that differ somewhat from those shown in this report. For example, dietary data from a research study of 242 children 6 to 23 months of age in Malawi (representing 320 dietary records) were obtained [37] (Dr. Christine Hotz, personal communication) and run through the same LP analyses as described here. The resulting solutions were similar to those for Ghana, but because the maximum amounts of certain foods consumed were greater in Malawi than in Ghana (e.g., green leafy vegetables, beans, and pumpkin), the diets included more of these foods and fewer animal-source foods (though iron supplements were still needed). Once a local assessment is completed using LP, further work is needed to develop recipes and dietary guidelines that can be used by caregivers. This will need to include careful attention to the amount of fluid needed in the overall diet, as explained in section 3.6.

7. Acknowledgments

This paper was commissioned by the WHO Department of Child and Adolescent Health and Development. We gratefully acknowledge statistical assistance from Janet M. Peerson and input from André Briend, Samuel Fomon, Ellen Piwoz, and Ekhard Ziegler. We thank the other investigators involved in the studies of dietary intake of infants from which the food lists and maximum amounts consumed were derived: in Bangladesh, J. E. Kimmons, E. Haque, J. Chakraborty, S. J. M. Osendarp, and K. H. Brown; in Ghana, A. Lartey, A. Manu, J. Peerson, and K. H. Brown; in Guatemala, K. H. Brown, M. C. Santizo, F. Begin, and B. Torun; in Honduras, L. Landa Rivera; in Peru, H. Creed de Kanashiro, K. H. Brown, G. Lopez de Romana, T. Lopez, and R. E. Black. We are also indebted to those who responded to the survey regarding replacement feeding of infants of HIV-positive mothers: Louise Kuhn, Zambia Exclusive Breastfeeding Study (ZEBS), Columbia University, USA; Anna Miller, Pediatric AIDS Foundation, Zimbabwe; Peter Iliff, Zvitambo Project, Zimbabwe; Ruth Nduati, Nairobi, Kenya; Dorothy Ochola-Odong, UNICEF, Uganda; Jane Muita, UNICEF, Malawi; Valeriane Leroy, DITRAME Plus ANRS, Abidjan, Côte d'Ivoire and University of Bordeaux, France; Ellen Piwoz, Academy for Educational Development, Washington and UNC-CDC Malawi BAN Study; and Ibou Thior, Harvard AIDS Institute Partnership for HIV Research and Education, Botswana.

References

1. World Health Organization (WHO). The World Health Organization's infant feeding recommendation. Wkly Epidemiol Rec 1995;17:117–220.
2. UNICEF/UNAIDS/WHO/UNFPA. HIV and infant feeding. Guidelines for decision-makers. Geneva: World Health Organization, 2003. Available at: http://www.who.int/child-adolescent-health/New_Publications/NUTRITION/HIV_IF_DM.pdf. Accessed September12, 2004.
3. Pan American Health Organization/World Health Organization. Guiding principles for complementary feeding of the breastfed child. Washington, DC: Pan American Health Organization, 2003.
4. Fomon SJ. Nutrition of normal infants. St. Louis, Mo, USA: Mosby, 1993.
5. Fomon SJ. Infant feeding in the 20th century: formula and beikost. J Nutr 2001;131:409S–20S.
6. American Academy of Pediatrics. Pediatric Nutrition Handbook. Chicago, Ill, USA: American Academy of Pediatrics, 2004.
7. Fuchs G, DeWier M, Hutchinson S, Sundeen M, Schwartz S, Suskind R. Gastrointestinal blood loss in older infants: impact of cow milk versus formula. J Pediatr Gastroenterol Nutr 1993;16:4–9.
8. Ziegler EE, Jiang T, Romero E, Vinco A, Frantz JA, Nelson SE. Cow's milk and intestinal blood loss in late infancy. J Pediatr 1999;135:720–6.
9. Fomon SJ, Ziegler EE, Nelson SE, Edwards BB. Cow milk feeding in infancy: gastrointestinal blood loss and iron nutritional status. J Pediatr 1981;98:540–5.
10. Briend A, Darmon N. Determining limiting nutrients by linear programming: a new approach to predict insufficient intakes from complementary foods. Pediatrics 2000;106:1288–9.
11. Darmon N, Ferguson E, Briend A. Linear and nonlinear programming to optimize the nutrient density of a population's diet: an example based on diets of preschool children in rural Malawi. Am J Clin Nutr 2002;75:245–53.
12. Briend A, Darmon N, Ferguson E, Erhardt JG. Linear programming: a mathematical tool for analyzing and optimizing children's diets during the complementary feeding period. J Pediatr Gastroenterol Nutr 2003;36: 12–22.
13. Nestel P, Briend A, de Benoist B, Decker E, Ferguson E, Fontaine O, Micardi A, Nalubola R. Complementary food supplements to achieve micronutrient adequacy for infants and young children. J Pediatr Gastroenterol Nutr 2003;36:316–28.
14. USAID Commodity Reference Guide. 1999. Available at: http://www.usaid.gov/our_work/humanitarian_assistance/ffp/crg/. Accessed September 12, 2004.
15. Kimmons JE, Dewey KG, Haque E, Chakraborty J, Osendarp S, Brown KH. Behavior-change trials to assess the feasibility of improving complementary feeding practices and micronutrient intake of infants in rural Bangladesh. Food Nutr Bull 2004, 25:228–38.
16. Lartey A, Manu A, Brown KH, Peerson JM, Dewey KG. A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. Am J Clin Nutr 1999;70: 391–404.
17. Brown KH, Santizo MC, Begin F, Torun B. Effect of supplementation with multiple micronutrients (MMN) and/or bovine serum concentrate (BSC) on the growth of low income, peri-urban Guatemalan infants and young children. FASEB J 2000;14:A534.
18. Domellof M, Cohen RJ, Dewey KG, Hernell O, Rivera LL, Lönnerdal B. Iron supplementation of breast-fed Honduran and Swedish infants from 4 to 9 months of age. J Pediatr 2001;138:679–87.
19. de Kanashiro HC, Brown KH, Lopez de Romana G, Lopez T, Black RE. Consumption of food and nutrients by infants in Huascar (Lima), Peru. Am J Clin Nutr 1990;52:995–1004.
20. World Food Dietary Assessment System, INFOODS. Available at http://www.fao.org/infoods/software_overview_en.stm. Accessed September 29, 2004.
21. Food and Agriculture Organization/World Health Organization/International Atomic Energy Agency (FAO/WHO/IAEA). Trace elements in human nutrition and health. Geneva: World Health Organization, 1996.
22. Weaver CM, Proulx WR, Heaney R. Choices for achieving adequate dietary calcium with a vegetarian diet. Am J Clin Nutr 1999;70(3 suppl):543S–8S.
23. Dewey KG, Brown KH. Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention

programs. Food Nutr Bull 2003;24:5–28.
24. Institute of Medicine. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press, 2001.
25. US Department of Agriculture. Continuing survey of food intakes by individuals, 1994–1996, 1998. National Technical Information Service CD-ROM, 2002. (NTIS Accession No. PB2000=96500027, 2002).
26. Israel-Ballard KA, Chantry CJ, Donovan R, Sheppard H, Carlson JR, Lonnerdal B, Sage AC, Abrams BF. Viral, nutritional, and bacterial safety of flash-heated and Pretoria pasteurized breast milk to prevent mother-to-child transmission of HIV in resource-poor countries. 2004 International AIDS Conference (abstract).
27. Institute of Medicine. Nutrition during lactation. Washington, DC: National Academy Press, 1991.
28. World Health Organization/UNICEF/United Nations Population Fund/United Nations Programme on HIV/AIDS (WHO/UNICEF/UNFPA/UNAIDS). HIV transmission through breastfeeding: a review of available evidence. Geneva: World Health Organization, 2004.
29. Dewey K, Beaton G, Fjeld C, Lönnerdal B, Reeds P. Protein requirements of infants and children. Eur J Clin Nutr 1996(suppl 1):S119–50.
30. Reeds PJ, Garlick PJ. Protein and amino acid requirements and the composition of complementary foods. J Nutr 2003;133:2953S–61S.
31. Phadke MA, Gadgil LB, Bharucha KE, Shrotri AN, Sastry J, Gupte NA, Brookmeyer R, Paranjape RS, Bulakh PM, Pisal H, Suryavanshi N, Shankar AV, Propper L, Joshi PL, Bollinger RC. Replacement-fed infants born to HIV-infected mothers in India have a high early postpartum rate of hospitalization. J Nutr 2003;133:3153–7.
32. Black RE, Lopez de Romana G, Brown KH, Bravo N, Bazalar OG, Kanashiro HC. Incidence and etiology of infantile diarrhea and major routes of transmission in Huascar, Peru. Am J Epidemiol 1989;129:785–99.
33. Ray G, Nath G, Reddy DCS. Extents of contamination of top milk and their determinants in an urban slum of Varanasi, India. Indian J Public Health 2000;44:111–7.
34. World Health Organization (WHO). Nutrient requirements for people living with HIV/AIDS. Report of a Technical Consultation. World Health Organization, Geneva, 13–15 May 2003. Available at: http://www.who.int/nut/publications.htm#hiv. Accessed September 12, 2004.
35. World Health Organization (WHO). Management of the child with a serious infection or severe malnutrition: guidelines for care at the first-referral level in developing countries. WHO/FCH/CAH/00.1. Geneva: World Health Organization, 2000.
36. Diop EHI, Dossou NI, Ndour MM, Briend A, Wade S. Comparison of the efficacy of a solid ready-to-use food and a liquid, milk-based diet for the rehabilitation of severely malnourished children: a randomized trial. Am J Clin Nutr 2003;78:302–7.
37. Hotz C, Gibson RS. Complementary feeding practices and dietary intakes from complementary foods amongst weanlings in rural Malawi. Eur J Clin Nutr 2001;55:841–9.