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Identifying micronutrient gaps in the diets of breastfed 6-11-month-old infants in Bangladesh, Ethiopia and Viet Nam using linear programming

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Alive & Thrive is a six-year (2009-2014) initiative to improve infant and young child feeding practices by increasing rates of exclusive breastfeeding and improving complementary feeding practices. The first two years of life provide a window of opportunity to prevent child deaths and ensure healthy growth and brain development. Alive & Thrive (A&T) aims to reach more than 16 million children under two years old in Bangladesh, Ethiopia, and Viet Nam through various delivery models. Learning will be shared widely to inform policies and programs throughout the world. Alive & Thrive is funded by the Bill & Melinda Gates Foundation and managed by FHI 360. Other members of the A&T consortium include BRAC, GMMB, International Food Policy Research Institute (IFPRI), Save the Children, University of California-Davis, and World Vision.

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Acronyms and Abbreviations

A&T	Alive & Thrive
DRI	Dietary Reference Intakes
FCT	food composition table
Fe	iron
IOM	Institute of Medicine
LP	linear programming
MNP	micronutrient powder
SQ-LNS	small-quantity, lipid-based nutrient supplement
Zn	zinc

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Executive Summary

Introduction
It is often difficult to meet nutritional needs during the period of complementary feeding (6-24 months of age) because infants and young children require high amounts of micronutrients in relatively small quantities of foods other than breast milk, especially at 6-11 months of age.

Objectives & Methods
The objective of these analyses was to use linear programming techniques to identify micronutrient gaps in the diets of breastfed 6-8- and 9-11-month-old children in the three Alive & Thrive target countries: Bangladesh, Ethiopia, and Viet Nam. Our first aim was to determine whether micronutrient requirements could be met using only unfortified local foods (regardless of cost or feasibility issues), and if not, which micronutrients were most limiting in local diets. We then explored options for meeting micronutrient needs that included fortified products, and compared the costs of the various scenarios.

Results
With unfortified foods alone, micronutrient requirements could be met for all three countries except for infants 6-8 months of age in Bangladesh and Ethiopia for whom there was a gap in meeting iron needs. However, all of these diets were unrealistic because 1) they required that liver be eaten daily, 2) most of them did not include the local staple food (rice or maize), and 3) the estimated daily cost of these diets (in U.S. cents) was relatively high: 16-22 in Bangladesh, 19-34 in Ethiopia, and 13-14 in Viet Nam.

With unfortified foods that included a minimal amount of the local staple food, micronutrient needs could be met for Viet Nam, but there were large gaps in meeting iron needs for 6-8-month-old infants in Bangladesh and Ethiopia. Again, these diets were unrealistic because 1) they required that liver be eaten daily, 2) they required that other animal-source foods (e.g., mussel, fish, goat) also be consumed daily, and 3) the estimated daily cost of these diets (in U.S. cents) was high: 20-23 in Bangladesh, 31-35 in Ethiopia, and 15-16 in Viet Nam.

With a diet that included unfortified foods from each of five food groups (a staple food, green leafy vegetables, legumes, egg, and fish or chicken), there were sizeable micronutrient gaps in all three countries and both age groups, particularly for iron and zinc. The estimated daily cost of these diets (in U.S. cents) was 20-30 in Bangladesh, 15-23 in Ethiopia, and 24-36 in Viet Nam.

By design, micronutrient needs were met in all diets that included fortified products (micronutrient powders [MNP] or small-quantity lipid nutrient supplements [SQ-LNS]).These diets did not include any animal-source foods (except for pork fat in Viet Nam, a cheap source of energy) because the linear programming tool was set up to minimize costs. The other foods that appeared in these diets were fat/oil or the local staple food – the lowest cost alternatives when micronutrient needs are being met by a fortified product. The estimated daily cost of the diets that included MNP (in U.S. cents) was 4-5 in Bangladesh, 4-6 in Ethiopia, and 3-6 in Viet Nam. The estimated daily cost of the diets that included SQ-LNS (in U.S. cents) was 11-12 in Bangladesh, 11-13 in Ethiopia, and 11-14 in Viet Nam.

Conclusions

These analyses illustrate the difficulty of meeting the nutritional needs of 6-11-month-old breastfed infants without the use of fortified products. Although micronutrient requirements could theoretically be met through diets based on unfortified foods alone, the cost of these diets was about three to eight times higher than the diets that included MNP, and up to three times higher than the diets that included SQ-LNS, depending on the country. Moreover, the diets based on unfortified foods are not likely to be feasible because they would require daily consumption of liver and other animal-source foods. The use of fortified products can ensure adequate micronutrient intake while minimizing cost.

1. Introduction

1.1. Challenges of meeting the nutritional needs of breastfed infants

The age range from 6 to 24 months is a critical period when children are especially vulnerable to malnutrition and infections, particularly in developing countries. Malnutrition during this period can lead to potentially irreversible long-term physical and mental damage. Nutrition interventions during this stage of life hold great potential in preventing these negative outcomes.

It is often difficult to meet the nutritional needs of children in this age range because they require high amounts of micronutrients but relatively small quantities (i.e., energy content) of foods other than breast milk. For this report, we have chosen to focus on the 6-8- and 9-11-month-old age groups because their energy needs are lowest yet their requirements for certain micronutrients (especially iron) are very high, making it especially difficult to deliver adequate amounts of micronutrients through their complementary foods.

1.2. Prevalence of poor child nutrition outcomes in Alive & Thrive target countries

The prevalence of childhood malnutrition is high in the three Alive & Thrive target countries of Bangladesh, Ethiopia, and Viet Nam. According to the most recent Demographic and Health Surveys, the rates of stunting, wasting, and underweight in these three countries in children < 5 years of age range from 33 to 51 percent, 8 to 17 percent, and 30 to 41 percent, respectively (Table 1). Additionally, the prevalence of anemia ranges from 34 to 54 percent.

Table 1: Prevalence (%) of nutritional indicators for children in Bangladesh, Ethiopia and Viet Nam[1]

	Bangladesh[a]	Ethiopia[b]	Viet Nam[c-e]
Stunting			
Height-for-age < -2 SD	43	51	33
Height-for-age < -3 SD	16	28	
Wasting			
Weight-for-height < -2 SD	17	12	8
Weight-for-height < -3 SD	3	4	
Underweight			
Weight-for-age < -2 SD	41	33	30
Weight-for-age < -3 SD	12	11	
Anemia			
Any anemia: < 11.0 g/dl	48	54	34
Mild: 10.0-10.9 g/dl		21	
Moderate: 7.0 – 9.9 g/dl		28	
Severe: < 7.0 g/dl		4	
Minimum acceptable diet (breastfed child who had at least the minimum dietary diversity and the minimum meal frequency)	11	3	

	Bangladesh[a]	Ethiopia[b]	Viet Nam[c-e]
Minimum dietary diversity (4 or more food groups. The food groups used for tabulation are: grains, roots and tubers; legumes and nuts; dairy products; flesh foods; eggs; vitamin A-rich fruits and vegetables; other fruits and vegetables)	12	4	
Minimum meal frequency (2 times for breastfed infants 6-8 months and 3 times for breastfed children 9-23 months)	81	42	

[a]2007 Bangladesh Demographic Health Survey
[b]2005 Ethiopia Demographic Health Survey
[c]2002 Viet Nam National Nutrition Survey conducted by NIN & General Statistical Office
[d]2001 Viet Nam Nutritional Surveillance
[e]2000 Viet Nam National Anemia Study conducted by NIN, CDC, UNICEF, and PAMM

2. Objectives

The objective of these analyses was to use linear programming techniques to identify micronutrient gaps in the diets of breastfed 6-11-month-old children in the three Alive & Thrive (A&T) countries: Bangladesh, Ethiopia, and Viet Nam. Our purpose was *not* to develop recipes or guidelines for complementary feeding, as this requires a different approach (goal programming rather than linear programming[2]). Our first aim was to determine whether micronutrient requirements could be met using only unfortified local foods (regardless of cost or feasibility issues), and if not, which micronutrients were most limiting in local diets. We then explored options for meeting micronutrient needs that included fortified products, and compared the costs of the various scenarios.

3. Methods

3.1. Linear programming

Linear programming (LP) is a technique that can be used to develop diets that meet nutritional requirements at the lowest possible cost. It has been used for decades for feeding domestic animals, but only recently has the technique been applied to human diets. 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, and 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 a list of locally available foods, their costs, and the typical amounts of each food consumed by children in the designated age range[3]. For this report, the age ranges used for the LP analyses were 6-8 and 9-11 months.

3.2. Micronutrients of interest

The micronutrients of focus for these analyses are listed below. These nutrients have been identified as the key "problem nutrients" during this age range[4], and there is adequate food composition information for most of them.

- Minerals
  - Calcium
  - Iron
  - Zinc
- Vitamins
  - Vitamin A
  - Thiamin
  - Riboflavin
  - Vitamin B6
  - Folate
  - Vitamin B12
  - Vitamin C

3.3. Linear programming scenarios

The following seven scenarios were explored for each age group of breastfed infants (6-8 months and 9-11 months) in each country:

1. "No constraints, unfortified" diet: unfortified complementary foods only, with no constraints on types of foods included
2. "Minimum staple food, unfortified" diet: unfortified complementary foods only, with a minimum quantity (30 percent of energy from complementary foods) of the country's typical staple food (rice for Bangladesh and Viet Nam, corn bread for Ethiopia) "forced" into the model, but otherwise no constraints on types of foods included
3. "Five food group, unfortified" diet: unfortified complementary foods only, with a minimum quantity of the typical staple food (as above), and including legumes; egg; fish or chicken; and green leafy vegetables every day (described below in Table 2)

Table 2: Composition of five food group unfortified diet scenario

Food type	% kcal from complementary foods	Food amount (kcal)	
		6-8 mo	9-11 mo
Staple food	30	61	92
Legume	25	51	77
Chicken egg	20	40	61
Fish (Bangladesh and Viet Nam) or chicken (Ethiopia)	20	40	61
Green leafy vegetable	5	10	15

4. "No constraints + MNP" diet: unfortified complementary foods + micronutrient powder (MNP) sachet
5. "Minimum staple food + MNP" diet: unfortified complementary foods, with a minimum quantity of the country's staple food "forced" into the model (as above) + MNP sachet
6. "No constraints + small-quantity lipid-based nutrient supplement (SQ-LNS) " diet: unfortified complementary foods + 20 g of a lipid-based nutrient supplement (e.g., Nutributter®)
7. "Minimum staple food + SQ-LNS" diet: unfortified complementary foods, with a minimum quantity of the country's staple food "forced" into the model (as above) + 20 g of Nutributter®

All scenarios considered breastfed infants only and assumed that 6-8- and 9-11-month-olds were receiving "average" amounts of breast milk (413 kcal/d and 379 kcal/d of breast milk, respectively[4]).

3.4. Data used to develop food lists, food prices, and nutrient composition of foods

Food lists and food prices were obtained from contacts in each country. The contacts for each country, how the data were collected for the food lists and food prices, and the food composition tables used to obtain the nutrient composition of each food are described in Table 3. Note that the food lists can be developed based on a relatively small (and non-representative) sample of children in each country, as long as the resulting list includes most of the nutrient-rich foods commonly available for infant feeding in each country. The food list information is not used to determine the amount of each food included in the linear programming analyses.

Table 3: Sources used for food lists, prices, and food composition

Country	Contacts for food list & prices	Source of data for food list	Source of data for food prices	Food composition tables used
Bangladesh	Helena Pachón Tina Sanghvi	Observation of 39 children from Chittagong and 39 children from Dhaka. June 2009	Food prices from Chittagong and Dhaka. June 2009	1. HarvestPlus Bangladesh Food Composition Table 2. USDA Nutrient Database
Ethiopia	Rosalind Gibson Yewelsew Abebe	Pilot study conducted in Sidama. June 2006	Food prices from Hawassa market. January 2010	1. USDA Nutrient Database 2. International Minilist
Viet Nam	Mai Tuyet Nhung	Observation and interview of 10 mothers in Danang City. September 2009	Foods priced at Metro Supermarket in Danang City. September 2009	1. USDA Nutrient Database 2. International Minilist

Table 4 compares the estimated costs of selected foods across the three countries. Foods were generally most expensive in Viet Nam; however, chicken eggs were most expensive in Bangladesh, and fish was most expensive in Ethiopia.

Table 4: Cost comparison of selected foods across all 3 countries

Food	Cost (US cents per 100 g)		
	Bangladesh	Ethiopia	Viet Nam
Potato	4	2	7
Sweet potato	1	3	7
Pumpkin	1	0.3	7
Banana	4	5	13
Chicken egg	43	23	19
Beef	32	28	68
Chicken	17	28	37
Fish	19	40	37
Oil	11	13	14

The macronutrient composition of SQ-LNS was based on Nutributter®, produced by Nutriset [Malaunay, France], which contains 118 kcal per 20 g sachet. The micronutrient composition of Nutributter® and MNP can be tailored to meet the needs of the target age group for the vitamins and minerals shown in section 3.2, with the possible exception of calcium. The cost of MNP was assumed to be $0.015 per day, and the cost of Nutributter ® was assumed to be $0.10 per day.

3.5. Food selection

Foods from the original food lists were excluded from the analyses if:

1. Nutrient composition could not be obtained for all of the 10 micronutrients of interest listed above
2. Prices of the foods were missing
3. A similar food was already in the model (e.g., if "rice [parboiled]" was in the model, "rice [sunned]" and "rice [puffed]" were excluded)

To maximize the possibility of meeting nutrient needs using unfortified local complementary foods, chicken, chicken liver, and chicken eggs were added to the food lists even if they were not listed as consumed by a given population, to create a "best case" scenario. Table 5 lists the foods that were included in the LP analyses for each country, and Table 6 lists the foods from the original food lists that were excluded. Of the various cow's milk options, powdered cow's milk was chosen rather than liquid cow's milk because the nutrient content (per 100 kcal) is virtually the same, but there is less risk of contamination with dry milk powder incorporated into the diet than with liquid milks (which are often fed by bottle).

Table 5: Foods included in the linear programming analyses

	Bangladesh	Ethiopia	Viet Nam
Cereals & Grains	Bread (loaf) Rice (parboiled, milled) Semolina Wheat flour (whole)	Barley flour roasted with sugar Corn (boiled) Corn (roasted, on cob) Corn bread (leavened) Corn bread (unleavened) Corn/wheat bread (50:50, unleavened) Corn/wheat bread (75:25, unleavened) Wheat bread (from refined processed white flour) Wheat bread (leavened) Wheat bread (unleavened)	Green bean noodles Rice (homemade) Rice noodles
Cookies & Cakes	Biscuit (salted) Biscuit (sweet)	N/A	Biscuits Wafers
Roots, Tubers, & Starches	Plantain Potato Sago Sweet potato (white flesh)	False banana Potato (boiled) Potato (roasted) Sweet potato (orange flesh)	Cassava Potato Sweet potato (orange flesh) Yam
Legumes, Nuts & Seeds	Cow pea Jackfruit seed Lentils	Red kidney beans	Black beans Kidney beans Lentils Lotus seed Peas Tofu Yellow soybeans
Vegetables (other than green leafy vegetables)	Onion Pumpkin	Green pepper Leek Pumpkin Spring onion	Carrots Pumpkin Squash
Green Leafy Vegetables	Indian spinach Jute plant tops Kolmee leaves	Kale*	Amaranth Cabbage Chinese cabbage Jute potherb Swamp cabbage Vine spinach
Fruits	Banana Jackfruit Lichi Mango Orange Tomato	Avocado Banana Guava Papaya	Apple Avocado Banana Grapes Guava Mango Papaya Passion fruit Pear Persimmon Sapodilla Tangerine Tomato Watermelon

*The price for kale could not be obtained in Ethiopia because it was not available in the market during the time of survey. Thus, its cost was calculated as the average price of all leafy greens in Bangladesh and Viet Nam.

	Bangladesh	Ethiopia	Viet Nam
Dairy Products & Eggs	Chicken eggs Powdered cow's milk	Cheese Powdered cow's milk Chicken eggs	Cheese Cream Powdered cow's milk Yogurt Chicken eggs Duck eggs Goose eggs
Meat & Poultry	Beef Chicken	Beef Chicken Goat	Beef Chicken Duck Frog Goat Mutton Pork
Organ Meats	Chicken liver Lamb liver	Chicken liver	Chicken heart Chicken liver Chicken gizzard Duck liver Pork liver Pork kidney
Fish & Shellfish	Boal fish Climbing fish Dragon fish Mrigal fish Sarputi fish	Fish^	Carp Clam Crab Eel Goby Mackerel Mussel Oyster Prawn
Beverages	N/A	N/A	Apple juice Grape juice Orange juice Passion fruit juice Pear juice Tangerine juice Coconut water
Fats & Oils	Soybean oil	Butter Corn oil	Butter Soybean oil Pork fat
Sweets	Sugar Sugar candy	Sugar	Chocolate Honey Soda Sugar

^The nutritional content of fish varies greatly depending on how it is eaten (with or without bones, with or without skin), but the food composition table for Ethiopia did not specify which of these was the basis for the nutrient content of the fish.

Table 6: Foods excluded from the linear programming analyses

	Bangladesh	Ethiopia	Viet Nam
Cereals & Grains	Rice (puffed)[a] Rice (sunned, milled)[a] Rice husk/bran [a] Wheat flour (coarse)[a] Wheat flour (refined)[a]	Corn porridge[c] Mixed cereal porridge[c]	Instant noodles[b] Rice porridge(homemade)[a] Rice flour (homemade)[a]
Cookies & Cakes		African cake[c]	
Roots, Tubers, & Starches		Enset root[c]	
Legumes, Nuts & Seeds		Peas[c]	Fresh beans[b]
Green Leafy Vegetables			
Fruits	Lime (sweet)[b]		Longan[b] Mang cut[b] Polemo[b] Thanh long[b]
Dairy Products & Eggs	Cow milk solids[a] Cow's milk (whole)[a]		
Meat & Poultry			Frog meat (dried flour)[b]
Organ Meats	Goat liver[c]		
Beverages		Coffee[d]	Avocado juice[b] Guava juice[b] Lemon juice[b] Longan juice[b] Mango juice[b] Papaya juice[b] Polemo juice[b] Thanh long juice[b] Watermelon juice[b]
Other			Fish sauce[e]

[a]Excluded because similar food already in model
[b]Excluded because missing FCT values
[c]Excluded because did not have price information
[d]Excluded because inappropriate for infant consumption
[e]Excluded because consumed in very small quantities

3.6. Constraints

3.6.1. Constraints on the maximum amounts of complementary foods consumed

The maximum amounts of each food that could be feasibly consumed by an infant each day were obtained from a table based on 90 percent of the maximum amount ever consumed by any child across five countries (Bangladesh, Ghana, Guatemala, Honduras, and Peru)[3]. The maximum intake across a variety of countries was used instead of maximum intakes specific to each country in order to be as generous as possible regarding the *potential* amounts of nutrient-rich foods consumed (including nutrient-dense foods that infants may not typically consume for cultural reasons).

3.6.2. Constraints on nutrient intake

For the nutrient requirements to be met, we chose the lower of: a) the Recommended Nutrient Intakes from WHO 2004[5], or b) the Recommended Dietary Allowances or Adequate Intakes from the Institute of Medicine (IOM) Dietary Reference Intakes (DRI)[6-9]. This choice was based on maximizing the possibility of meeting nutrient needs using local unfortified foods. The values used are listed in Table 7.

Table 7: Nutrient requirements used for analyses and their sources

Nutrient	Recommended Nutrient Intake	Source
Vitamin A (µg RE/day)	400	WHO 2004
Folate (µg/day)	80	(WHO & IOM values are the same)
Riboflavin (mg/day)	0.4	"
Thiamin (mg/day)	0.3	"
Vitamin B6 (mg/day)	0.3	"
Vitamin B12 (µg/day)	0.7	"
Vitamin C (mg/day)	30	WHO 2004
Calcium (mg/day)	270	IOM
Iron (mg/day)	9.3	WHO 2004
Zinc (mg/day)	3	IOM

The micronutrient content of breast milk that was assumed is described in Table 8.

Table 8: Micronutrient content of breast milk*

Nutrient	Amount/ 100 g of breast milk
Energy (kcal)[10]	59
Vitamin A (µg RE)	50
Folate (µg)	8.81
Riboflavin (mg)	0.036
Thiamin (mg)	0.022
Vitamin B6 (mg)	0.0096
Vitamin B12 (µg)	0.1
Vitamin C (mg)	4.1
Calcium (mg)	29
Iron (mg)	0.031
Zinc (mg)[11]	0.1 (5-8 mo postpartum) 0.08 (≥9 mo postpartum)

*World Health Organization 1998, unless otherwise indicated.

The bioavailability of breast milk calcium, iron, and zinc was assumed to be 61 percent[6], 34 percent[12], and 50 percent[13] respectively. The amounts of micronutrients that complementary foods had to supply were calculated based on the values in Table 7 minus the values listed in Table 8. Since the micronutrient composition of SQ-LNS and MNP can be tailored to meet the vitamin and mineral needs of a target age group, with the possible exception of calcium, it was assumed that all micronutrient needs could be met through SQ-LNS or MNP in scenarios 4-7. Therefore, the solver function only had to obtain a solution to ensure that energy requirements were met at the lowest cost. Although it is difficult to create fortified products with high levels of calcium, this was not a problem for our scenarios because the amount of bioavailable calcium provided by breast milk (which contains ~29 mg of calcium/100 g, of which an estimated 61 percent is absorbed) is sufficient to meet the needs of a 6-12-month-old infant whose breast milk intake is "average".

Energy requirements, taken from Dewey & Brown (2003)[4], are presented in Table 9.

Table 9: Energy requirements used for analyses[4]

Age group (mo)	Total energy requirements (kcal/day)	Estimated milk energy intake, assuming average breast milk intake (kcal/day)	Energy expected from complementary foods (kcal/day)
6-8	615	413	202
9-11	686	379	307

3.6.3. Other constraints

To avoid LP "solutions" that contained trivial amounts of various foods, foods that appeared in the initial solutions with amounts < 5 grams were excluded and the LP analysis was rerun. This process was repeated until a solution that did not have any food amounts less than 5 grams was found. Exceptions were oil and organ meats, because these foods are high in energy or micronutrient density.

3.7. Bioavailability assumptions

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 percent from plant-source foods and 11 percent from animal-source foods[14, 15]. Zinc absorption was estimated based on the phytate-to-zinc molar ratio of the diet, with 30 percent absorption from foods having a phytate-to-zinc molar ratio ≤ 18 and 22 percent absorption from foods having a phytate-to-zinc ratio > 18[16]. The absorption of calcium was assumed to be 25 percent for legumes, roots or tubers, and grains; 5 percent for foods with high oxalate content (e.g., spinach); and 32 percent for all other foods[14].

4. Results of linear programming runs

Initial results are presented in Tables 10-15 below and include estimated costs and any nutrient gaps remaining in the final solution for each scenario. These results assume that a child would consume the listed foods in their respective amounts *every day*. Thus, the solutions are *not* meant to be *prescriptive*.

Table 10: Linear programming solutions for 6-8-month-old breastfed infants in Bangladesh

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	413 kcal Breast milk 5 g Cow peas 130 g Pumpkin 40 g Jute plant tops 35 g Chicken liver 75 g Mrigal fish	0.22	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.82 mg Gap = -0.11 mg Percentage of requirement met: 88%
2	Minimum staple food, unfortified	413 kcal Breast milk 16 g Rice 40 g Jute plant tops 35 g Chicken liver 69 g Mrigal fish	0.20	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.72 mg Gap = -0.21 mg Percentage of requirement met: 78%
3	Five food group, unfortified	413 kcal Breast milk 16 g Rice 14 g Lentils 44 g Spinach 28 g Chicken egg 32 g Mrigal fish	0.20	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.35 mg Gap = -0.58 mg Percentage of requirement met: 37% *Zinc* RNI for bioavailable Zn = 1 mg Bioavailable Zn content of diet = 0.82 mg Gap = -0.18 mg Percentage of requirement met: 82%
4	No constraints + MNP	413 kcal Breast milk 23 g Soybean oil 1 sachet of MNP	0.04	None
5	Minimum staple food + MNP	413 kcal Breast milk 54 g Rice 1 sachet of MNP	0.04	None
6	No constraints + SQ-LNS	413 kcal Breast milk 10 g Soybean oil 20 g SQ-LNS	0.11	None
7	Minimum staple food + SQ-LNS	413 kcal Breast milk 17 g Rice 2 g Soybean oil 20 g SQ-LNS	0.11	None

Table 11: Linear programming solutions for 9-11-month-old breastfed infants in Bangladesh

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	379 kcal Breast milk 59 g Cow peas 7 g Pumpkin 40 g Jute plant tops 35 g Chicken liver 38 g Mrigal fish	0.16	None
2	Minimum staple food, unfortified	379 kcal Breast milk 25 g Rice 9 g Cow peas 130 g Pumpkin 40 g Jute plant tops 35 g Chicken liver 75 g Mrigal fish	0.23	None
3	Five food group, unfortified	379 kcal Breast milk 25 g Rice 22 g Lentils 67 g Spinach 43 g Chicken egg 48 g Mrigal fish	0.30	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.48 mg Gap = -0.45 mg Percentage of requirement met: 52%
4	No constraints + MNP	379 kcal Breast milk 91 g Wheat flour (whole) 1 sachet of MNP	0.04	None
5	Minimum staple food + MNP	379 kcal Breast milk 82 g Rice 1 sachet of MNP	0.05	None
6	No constraints + SQ-LNS	379 kcal Breast milk 21 g Soybean oil 20 g SQ-LNS	0.12	None
7	Minimum staple food + SQ-LNS	379 kcal Breast milk 27 g Rice 10 g Soybean oil 20 g SQ-LNS	0.12	None

Table 12: Linear programming solutions for 6-8-month-old breastfed infants in Ethiopia

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	413 kcal Breast milk 35 g Corn/wheat bread 75:25 (unleavened) 20 g Spring onion 40 g Goat 35 g Chicken liver	0.34	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.87 mg Gap = -0.06 mg Percentage of requirement met: 94%
2	Minimum staple food, unfortified	413 kcal Breast milk 19 g Corn bread (leavened) 8 g Corn/wheat bread 75:25 (leavened) 20 g Spring onion 40 g Goat 35 g Chicken liver	0.31	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.77 mg Gap = -0.16 mg Percentage of requirement met: 82%
3	Five food group, unfortified	413 kcal Breast milk 19 g Corn bread (leavened) 40 g Red kidney beans 36 g Kale 26 g Chicken egg 17 g Chicken	0.15	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.25 mg Gap = -0.68 mg Percentage of requirement met: 26% *Zinc* RNI for bioavailable Zn = 1 mg Bioavailable Zn content of diet = 0.68 mg Gap = -0.32 mg Percentage of requirement met: 68% *Vitamin B6* RNI for Vitamin B6 = 0.3 mg Vitamin B6 content of diet = 0.27 mg Gap = -0.03 mg Percentage of requirement met: 90%
4	No constraints + MNP diet	413 kcal Breast milk 23 g Corn oil 1 sachet of MNP	0.04	None
5	Minimum staple food + MNP	413 kcal Breast milk 22 g Corn bread (leavened) 15 g Corn oil 1 sachet of MNP	0.04	None
6	No constraints + SQ-LNS	413 kcal Breast milk 9 g Corn oil 20 g SQ-LNS	0.11	None
7	Minimum staple food + SQ-LNS	413 kcal Breast milk 20 g Corn bread (leavened) 2 g Corn oil	0.11	None

Table 13: Linear programming solutions for 9-11-month-old breastfed infants in Ethiopia

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	379 kcal Breast milk 48 g Corn/wheat bread 75:25 (unleavened) 31 g Potato (roasted) 80 g Red kidney beans 20 g Spring onion 35 g Chicken liver	0.19	None
2	Minimum staple food, unfortified	379 kcal Breast milk 29 g Corn bread (leavened) 40 g Corn/wheat bread 75:25 (unleavened) 20 g Spring onion 40 g Goat 35 g Chicken liver	0.35	None
3	Five food group, unfortified	379 kcal Breast milk 29 g Corn bread (leavened) 60 g Red kidney beans 55 g Kale 40 g Chicken egg 26 g Chicken	0.23	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.33 mg Gap = -0.60 mg Percentage of requirement met: 35% *Zinc* RNI for bioavailable Zn = 1 mg Bioavailable Zn content of diet = 0.83 mg Gap = -0.17 mg Percentage of requirement met: 83%
4	No constraints + MNP diet	379 kcal Breast milk 35 g Corn oil 1 sachet of MNP	0.06	None
5	Minimum staple food + MNP	379 kcal Breast milk 33 g Corn bread (leavened) 23 g Corn oil 1 sachet of MNP	0.05	None
6	No constraints + SQ-LNS	379 kcal Breast milk 21 g Corn oil 20 g SQ-LNS	0.13	None
7	Minimum staple food + SQ-LNS	379 kcal Breast milk 31 g Corn bread (leavened) 10 g Corn oil 20 g SQ-LNS	0.12	None

Table 14: Linear programming solutions for 6-8-month-old breastfed infants in Viet Nam

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	413 kcal Breast milk 15 g Kidney beans 6 g Amaranth 10 g Duck liver 25 g Pork liver 14 g Pork fat	0.14	None
2	Minimum staple food, unfortified	413 kcal Breast milk 53 g Rice 11 g Squash 7 g Tomato 7 g Watermelon 12 g Duck liver 23 g Pork liver 8 g Pork fat	0.15	None
3	Five food group, unfortified	413 kcal Breast milk 47 g Rice 29 g Yellow soybean 27 g Jute potherb 26 g Chicken egg 30 g Fish (Mackerel)	0.24	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.33 mg Gap = -0.60 mg Percentage of requirement met: 36% *Zinc* RNI for bioavailable Zn = 1 mg Bioavailable Zn content of diet = 0.71 mg Gap = -0.29 mg Percentage of requirement met: 71%
4	No constraints + MNP diet	413 kcal Breast milk 22 g Pork fat 1 sachet of MNP	0.03	None
5	Minimum staple food + MNP	413 kcal Breast milk 47 g Rice 16 g Pork fat 1 sachet of MNP	0.05	None
6	No constraints + SQ-LNS	413 kcal Breast milk 9 g Pork fat 20 g SQ-LNS	0.11	None
7	Minimum staple food + SQ-LNS	413 kcal Breast milk 47 g Rice 3 g Pork fat 20 g SQ-LNS	0.12	None

Table 15: Linear programming solutions for 9-11-month-old breastfed infants in Viet Nam

	Scenario	Solution	Cost (US $)	Unmet nutrient requirements
1	No constraints, unfortified	379 kcal Breast milk 24 g Duck liver 10 g Pork liver 20 g Pork fat	0.13	None
2	Minimum staple food, unfortified	379 kcal Breast milk 71 g Rice 15 g Duck liver 13 g Pork liver 7 g Chicken heart 7 g Mussel 8 g Pork fat	0.16	None
3	Five food group, unfortified	379 kcal Breast milk 71 g Rice 44 g Yellow soybeans 41 g Jute potherb 40 g Chicken egg 46 g Fish (Mackerel)	0.36	*Iron* RNI for bioavailable Fe = 0.93 mg Bioavailable Fe content of diet = 0.46 mg Gap = -0.47mg Percentage of requirement met: 49% *Zinc* RNI for bioavailable Zn = 1 mg Bioavailable Zn content of diet = 0.86 mg Gap = -0.14 mg Percentage of requirement met: 86%
4	No constraints + MNP diet	379 kcal Breast milk 26 g Pork fat 1 sachet of MNP	0.04	None
5	Minimum staple food + MNP	379 kcal Breast milk 71 g Rice 16 g Pork fat 1 sachet of MNP	0.06	None
6	No constraints + SQ-LNS	379 kcal Breast milk 13 g Pork fat 20 g SQ-LNS	0.11	None
7	Minimum staple food + SQ-LNS	379 kcal Breast milk 71 g Rice 3 g Pork fat	0.14	None

These results indicate the following:

a. **Scenario 1: No constraints, unfortified diet.** With unfortified foods alone, and without "forcing" any of the local staple food into the diet, micronutrient requirements could be met for all three countries except for infants 6-8 months of age in Bangladesh (for whom there was a 12 percent gap in meeting iron needs) and Ethiopia (for whom there was a 6 percent gap in meeting iron needs). However, all of these diets included at least 34 grams of liver (chicken, duck, or pork). In Bangladesh, the diets included 38-75 grams of fish per day in addition to the chicken liver. These diets are not realistic because neither the Bangladesh nor the Viet Nam diets included any of the local staple food (rice), and all diets required eating liver daily. The estimated daily cost of these diets (in U.S. cents) was 16-22 in Bangladesh, 19-34 in Ethiopia, and 13-14 in Viet Nam.

b. **Scenario 2: Minimum staple food, unfortified diet.** With unfortified foods that included a minimal amount of the local staple food, micronutrient needs could be met for Viet Nam, but there was a gap of 22 percent in meeting iron needs in Bangladesh for 6-8-month-old infants and a gap of 18 percent in meeting iron needs in Ethiopia for 6-8-month-old infants. As with scenario 1, all diets included 35 grams of liver (except for 9-11-month-old Vietnamese infants, for whom this diet included 28 grams of liver, 7 grams of chicken heart, and 7 grams of mussel). In addition to the liver, the diets for Bangladesh included 69-75 grams of fish, and the diets for Ethiopia included 40 grams of goat meat per day. Thus, these diets are also not realistic because they all require daily consumption of liver, as well as additional animal-source food in all cases. The estimated daily cost of these diets (in U.S. cents) was 20-23 in Bangladesh, 31-35 in Ethiopia, and 15-16 in Viet Nam.

c. **Scenario 3: Five food group, unfortified diet.** With the five food group, unfortified dietary that includes the staple food and a variety of nutrient-rich foods consumed daily (green leafy vegetables, legumes, egg and fish or chicken), there are sizeable micronutrient gaps in all three countries and both age groups. At 6-8 months, the shortfall in iron ranges from 63 to 74 percent of needs, and the shortfall in zinc ranges from 18 to 32 percent of needs. At 9-11 months, the shortfall in iron is 48-65 percent of needs. There is no shortfall in zinc in Bangladesh at this age, but in Ethiopia there is a shortfall of 17 percent and in Viet Nam there is a shortfall of 14 percent. In addition, in the Ethiopia solutions there is a 10 percent gap in vitamin B6 for infants 6-8 months of age. The estimated daily cost of these diets (in U.S. cents) was 20-30 in Bangladesh, 15-23 in Ethiopia, and 24-36 in Viet Nam.

d. **Scenarios 4-7 all include a fortified product (MNP or SQ-LNS).** By design, micronutrient needs are met in all four scenarios in all countries (including calcium, because the need for absorbable calcium can be met by the amount of breast milk assumed in these models). These diets do not include any animal-source foods (except for pork fat in Viet Nam, a cheap source of energy). This is because animal-source foods are generally expensive, and the linear programming analyses are set up to minimize cost. The other foods that appear in these diets are fat/oil or the local staple food because these are the lowest cost alternatives when micronutrient needs are being met by a fortified product. The estimated daily cost of the diets that included MNP (in U.S. cents) was 4-5 in Bangladesh, 4-6 in Ethiopia, and 3-6 in Viet Nam. The estimated daily cost of the diets that included SQ-LNS (in U.S. cents) was 11-12 in Bangladesh, 11-13 in Ethiopia, and 11-14 in Viet Nam.

5. Limitations

The limitations of these analyses include the following:

1. The foods included in the linear programming analyses do not include all of the foods that could be consumed by 6-11-month-old infants. Some foods are missing due to missing food prices or nutrient composition information, and other foods may be missing if they were not mentioned during preparation of the food lists or not utilized in infant feeding. It is possible that some of these excluded foods could be good sources of nutrients, in particular, goat liver in Bangladesh, dried frog meat flour in Viet Nam, and peas in Ethiopia. However, their inclusion is unlikely to change the results very much because foods of similar nutrient quality were included in the analyses (e.g., chicken or pork liver instead of goat liver).

2. Dark green leafy vegetables vary widely in their contents of certain micronutrients; therefore, it is possible that the inclusion of additional varieties of dark green leafy vegetables (in analyses that included only a few types of dark green leafy vegetables, i.e., those for Bangladesh and Ethiopia) may have yielded slightly different results.

3. Food price information fluctuates seasonally and annually, and various assumptions had to be made regarding prices for certain foods per 100 grams. In addition, the costs assumed for MNP and SQ-LNS are the approximate cost of the ingredients and packaging, and do not include the cost of distribution; moreover, costs of fortified products can vary widely depending on the site and scale of production. Thus, the cost estimates of the diets should be considered crude approximations.

4. These analyses are based on meeting micronutrient needs, and do not take into account the recommended intake of certain macronutrients such as essential fatty acids. The recommendations for dietary intake of essential fatty acids are not as well established as those for micronutrients. This is an active area of research, and future analyses that take essential fatty acid intake into account may generate different results (especially with regard to the adequacy of diets with MNP vs. SQ-LNS).

6. Conclusions

These analyses illustrate the difficulty of meeting the nutritional needs of 6-11-month-old breastfed infants without the use of fortified products. Although micronutrient requirements could theoretically be met through a "no constraints scenario" diet based on unfortified foods alone, the cost of these diets (scenarios 1 & 2) was about three to eight times higher than the diets that included MNP, and up to three times higher than the diets that included SQ-LNS, depending on the country. Moreover, the "no constraints scenario" diets based on unfortified foods are not likely to be feasible because they would require daily consumption of liver. With the dietary scenario that included unfortified foods from five food groups (including daily consumption of egg, plus fish or chicken), nutrient intake fell well short of the needs for iron and zinc in all three countries, and the cost of these diets was still about 4 to 9 times higher than the diets that included MNP and 1.4 to 3.3 times higher than the diets that included SQ-LNS. Thus, the use of fortified products can ensure adequate micronutrient intake while minimizing cost. The cost of the diets that included the fortified products is the total cost, including the cost of the fortified product, but the cost to the household would be considerably lower if the fortified product was provided free of charge or at a subsidized price via donor- or government-supported programs.

It is important to reiterate that the “diets” shown in section 4 above are intended only to illustrate the challenges of meeting micronutrient needs at this age, and are *not* meant to be used for diet planning. For example, the “diets” that resulted from the linear programming analyses for scenarios 4-7 are lacking in dietary diversity (e.g., fruits and vegetables) because the program is designed to minimize cost. Formulation of dietary recommendations requires a different programming approach than used herein (goal programming rather than linear programming). Adding purchased fruits and vegetables to diets that include the fortified products would increase their cost, though not as much as including animal-source foods in the quantities needed to meet micronutrient needs. Because encouraging dietary diversity is a key message in any program aiming to improve infant and young child nutrition, further work using techniques such as goal programming is needed to design diets that are affordable and diverse using a combination of nutritious local foods and fortified products. This work should also explore whether it is possible to reach nutrient targets when using a “flexible” schedule (rather than daily) for consumption of fortified products.

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