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The use of linear programming to determine whether a formulated complementary food product can ensure adequate nutrients for 6- to 11-month-old Cambodian infants[1–3]

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ABSTRACT

Background: A new software tool, Optifood, developed by the WHO and based on linear programming (LP) analysis, has been developed to formulate food-based recommendations.

Objective: This study discusses the use of Optifood for predicting whether formulated complementary food (CF) products can ensure dietary adequacy for target populations in Cambodia.

Design: Dietary data were collected by 24-h recall in a cross-sectional survey of 6- to 11-mo-old infants (*n* = 78). LP model parameters were derived from these data, including a list of foods, median serving sizes, and dietary patterns. Five series of LP analyses were carried out to model the target population's baseline diet and 4 formulated CF products [WinFood (WF), WinFood-Lite (WF-L), Corn-Soy-Blend Plus (CSB+), and Corn-Soy-Blend Plus Plus (CSB++)], which were added to the diet in portions of 33 g/d dry weight (DW) for infants aged 6–8 mo and 40 g/d DW for infants aged 9–11 mo. In each series of analyses, the nutritionally optimal diet and theoretical range, in diet nutrient contents, were determined.

Results: The LP analysis showed that baseline diets could not achieve the Recommended Nutrient Intake (RNI) for thiamin, riboflavin, niacin, folate, vitamin B-12, calcium, iron, and zinc (range: 14–91% of RNI in the optimal diets) and that none of the formulated CF products could cover the nutrient gaps for thiamin, niacin, iron, and folate (range: 22–86% of the RNI). Iron was the key limiting nutrient, for all modeled diets, achieving a maximum of only 48% of the RNI when CSB++ was included in the diet. Only WF and WF-L filled the nutrient gap for calcium. WF-L, CSB+, and CSB++ filled the nutrient gap for zinc (9- to 11-mo-olds).

Conclusions: The formulated CF products improved the nutrient adequacy of complementary feeding diets but could not entirely cover the nutrient gaps. These results emphasize the value of using LP to evaluate special CF products during the intervention planning phase. The WF study was registered at controlled-trials.com as ISRCTN19918531.
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INTRODUCTION

Adequate nutrition in early life is fundamental for physical and cognitive development (1). Young children are particularly vulnerable to inadequate nutrition during the complementary feeding period from 6 to 24 mo of age when nutrient needs are high to support rapid rates of growth, and breast milk alone will not meet their nutritional requirements (2). The diets of young children, in resource constrained environments are often low in vitamin A, iron, zinc, and calcium (1, 3, 4).

At this time in life, it is critical to provide a nutritionally adequate diet to avoid long-term negative consequences in adult life on health and human resource potential (5). To help develop population-specific food-based recommendations for the purpose of improving complementary feeding diets, a mathematical approach based on linear programming (LP)[4] analysis was recently developed (6–8), which will soon be available to download from the WHO website as the user-friendly software–Optifood. LP has also proven useful at determining the cost-effectiveness of food fortification to meet nutrient requirements in populations (9), at formulating new food products based on local commodities (10), and at determining the need for supplements to ensure adequate nutrient intake in specific vulnerable populations (11). An option not yet explored is how LP can be used, during initial nutrition intervention program planning phases, to predict whether specially formulated complementary food (CF) products will cover nutrient gaps in local CF diets.

In Cambodia, the prevalence of malnutrition among preschool children has remained unchanged for the past 10 y. The 2010 Cambodian Demographic and Health Survey concluded that 40% of children younger than 5 y were stunted; 28% were underweight

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[4] Abbreviations used: ASF, animal-source foods; CF, complementary food; CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; DW, dry weight; LP, linear programming; RNI, Recommended Nutrient Intake; WF, WinFood; WF-L, WinFood-Lite.

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and 11% were wasted. The stunting rate rises as the age at which the child is introduced to CF increases (12).

The overall aim of the WinFood project was to develop nutritionally improved food products for infants and young children based on the use of locally available foods. The WinFood study developed 2 different formulated CF products: WinFood (WF) and WinFood-Lite (WF-L). WF contains rice, dried small fish, and edible spiders; WF-L contains rice and dried small fish and is fortified with a mineral and vitamin premix. These products were compared with Corn-Soy-Blend Plus (CSB+) and Corn-Soy-Blend Plus Plus (CSB++) in a single-blinded randomized trial with growth and iron status as the primary outcomes (13). CSB+ and CSB++ are fortified blended foods, distributed by World Food Program and other organizations, for the prevention and treatment of moderate acute malnutrition, respectively. The objective of this study was to evaluate, with the use of the LP approach, whether these specially formulated CF products would ensure a nutritionally adequate CF diet for 6- to 11-mo-old Cambodian infants.

SUBJECTS AND METHODS

Study design

This study was based on secondary cross-sectional dietary and anthropometric data collected from 6- to 11-mo-old infants living in 7 communes in PeaRieng district (Prey Veng Province, Cambodia) in November and December 2010. In this study, these data were analyzed by using LP to theoretically determine whether 4 formulated CF products would ensure dietary adequacy for 6- to 8-mo-old and 9- to 11-mo-old infants. Five series of LP models were run: 1 baseline model (without formulated food products) and then 1 series each for the 4 formulated food product models.

Subjects and sampling

In the original cross-sectional survey, all infants aged 6–15 mo (n = ∼800) from the 7 communes in PeaRieng district were invited to participate. Of those who participated (n = 567), 110 infants aged 6–15 mo were randomly selected to participate in a dietary-assessment substudy. All dietary data collected from the 6- to 11-mo-old infants in this substudy (n = 78) were included in the current study. Ethical approval was obtained from the National Ethics Committee for Health Research, Ministry of Health, the Royal Government of Cambodia, reference no. 151 NEHR (28 October 2010), and consultative approval was obtained from the Danish National Committee on Biomedical Research Ethics.

Survey data

Quantitative dietary data were collected by using a single 24-h dietary recall by 8 trained assistants who were fluent in the local language. At a population level, the 24-h dietary recalls were collected on all days of the week except Saturday and Sunday. During the interview, primary caregivers were asked to recall all foods and beverages consumed by their infants in the past 24 h. To help identify the foods consumed, pictures of food items and food models were shown to the caregiver so that she or he could point out the food items. The names of local dishes consumed were also recorded. The amount of each food item consumed was estimated from real food models. Mothers were asked to show the amount of food consumed by her child, which was then weighed on a scale (Dougguan Machinery Import and Export Co Ltd; precision to 0.1g) and recorded. To convert composite dishes into their individual ingredients, individual recipes were obtained from the Cambodian National food-consumption survey, which was carried out 6 mo later in Cambodia (unpublished data available from the Fishery Administration, Ministry of Agriculture, Forestry and Fisheries, accessed September 2012). For each dish, the author (JKHS) selected 5 similar recipes, which had the same name and contained the same raw ingredients as the recalled recipe, although the species of fish in the fish dishes could differ. The average recipes were created by calculating the mean weight for each raw ingredient divided by the mean weight of all the cooked dishes. Recipes, for 3 dishes (pork porridge, chicken porridge, and fish porridge), which were consumed by 37% of the infants, were not available from the national consumption survey. These dishes are often procured as ready to eat foods from local markets. Therefore, 3 local cooks were asked to prepare each of the 3 porridges. All raw ingredients and the final cooked porridge were weighed and recorded. The recipe conversion factor, for each ingredient, was calculated (raw ingredient weight/cooked porridge weight) and averaged across cooks to produce the ingredient conversion factors for each average porridge recipe.

Anthropometric measurements (weight and length) were made by 2 trained enumerators. Weight was measured to the nearest 100 g with an electronic scale (SECA scale), and length was measured to the nearest 0.1 cm (wooden length board was borrowed from World Food Program). General sociodemographic data were also collected by using a structured questionnaire.

The CF products

The WinFood products, WF and WF-L, were developed and produced in Cambodia based on locally available foods. Both products were based on white rice, which also is used in the rice porridge *bor-bor*, traditionally used for complementary feeding. Both products contained a proportion of animal-source food (ASF). The WF product was 14% dry weight (DW) ASF (small indigenous fish species with bones (*Esomus longmanus* and *Paralaupuca typus*) and the edible spider (*Haplopema sp.*). This spider is traditionally consumed in Cambodia and is available in local food markets. The WF-L contained 10% DW ASF (a variety of small fish species) and was fortified with a mineral and vitamin premix (**Table 1**). The fish in both products was initially sun dried, and the spiders were heat dried in an oven. Both products were processed by grinding ingredients to powders, mixing, and precooking by extrusion. The products were tested for microbial loads at the Pasteur Institute, Phnom Penh. The CSB products were provided by the World Food Program. The CSB+ (14) was distributed to all children in a Mother-Child-Health program, and CSB++ (15) was distributed for the treatment of moderately acutely malnourished children in Cambodia (16). The food composition and nutrient composition of all 4 formulated CF products are summarized in Table 1 and **Table 2**.

Analysis and data preparation

All analyses were done on infants stratified into 2 age groups (ie, 6–8 and 9–11 mo) because of age group differences in energy requirements.

TABLE 1
Food composition of the intervention foods per 100 g dry weight[1]

	WF[2]	WF-L[2]	CSB++	CSB+[3]
	%	%	%	%
Rice, white, milled	77	79	—	—
Fish, *Esomus longimanus*[4]	6.1	—	—	—
Fish, *Paralaubuca typus*[4]	6.1	—	—	—
Spider, *Haplopelma sp.*[4]	1.8	—	—	—
Fish mix[4]	—	9.5	—	—
Mineral and vitamin mix	—	1.7	1.7	1.4
Vegetable oil	4.8	4.8	3.0	8.5
Sugar	4.8	4.8	9.0	8.5
Maize (white or yellow)	—	—	58	65
Dehulled soya	—	—	20	—
Whole soya	—	—	—	20
Skim milk powder	—	—	8	—

[1] CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; WF, WinFood; WF-L, WinFood-Lite.

[2] WF and WF-L products were precooked by extrusion, similar to the processing of CSB products.

[3] Included sugar added by WFP-Cambodia and oil distributed in separate sachets to be added to the daily rations following WFP product specifications version 1.1 2010 (14).

[4] Edible parts of the fish were used, obtained by traditional cleaning practices in Cambodia. Edible parts include bones and head (17). For spiders, all parts were included as edible, following traditional consumption practices.

Development of modeled diets

All analyses were done by using Optifood (18). Five series of LP models were developed to model baseline diets and then baseline diets plus one of each of the intervention foods (WF, WF-L, CSB+, and CSB++). In each series of analyses, the LP models from Optifood's modules I to III (18) were used to *1*) check model parameters (Module I analyses), *2*) formulate the nutritionally "best diet" for each target group (Module II analyses), and *3*) estimate the tails of each nutrient intake distribution at baseline and then after successful adoption of each of the intervention foods [Module III analyses; which minimizes (worst-case scenario) and maximizes (best-case scenario) the nutrient content of modeled diets for each nutrient] (18). The nutrient goals (Module II analyses) and dietary adequacy (Module III analyses) were defined by using the FAO/WHO Recommended Nutrient Intakes (RNIs), for all nutrients except zinc (19, 20). For zinc, the International Zinc Nutrition Consultative Group RNIs were used (21). Moderate bioavailability was assumed for zinc, and 10% absorption was assumed for iron.

"Problem nutrients" were defined as nutrients that did not achieve 100% of their RNI in the modeled "best-case scenario" diets (ie, Module III; upper tail of the modeled nutrient intake distribution). Dietary adequacy, for each nutrient (ie, accepted percentage of the population at risk of an inadequate nutrient intake), was defined as >65% of its RNI in the "worst-case scenario" analyses (Module III; lower tail of the modeled nutrient intake distribution).

Preparation of model parameters

Data from the dietary assessment survey defined the model parameters, which included the list of foods modeled, the food serving sizes, and food patterns (**Tables 3** and **4**). The list of foods included in each model was noncondiment foods consumed by ≥5% of the children and nutrient-dense foods consumed by <5% of the children (Table 3). The serving size, for each food, was defined as the median serving size for children who consumed the food in each age group. To define model parameters for weekly food-consumption patterns, for food groups, and subfood groups with the use of 24-h dietary-recall data, 2 assumptions were made: *1*) food patterns remain relatively statistic over 7 d for each individual and *2*) overestimation errors are balanced by underestimation errors at the population level. In contrast, constraints on the maximum number of servings per week, for individual foods, were defined by the percentage of children who consumed them by using the distribution of a sum of binomial random variables. Specifically, the maximum number of servings per week was defined as 1, 2, 3, 4, 5, 6, or 7 when 0–5%, 6–12%, 13–22%, 23–34%, 35–47%, 48–65%, and 66–100%, respectively, of the children consumed the food. The nutrient contents per 100 g, for each modeled food item, were mainly obtained from the USDA (22), Vietnamese food-composition table (23), and Thai food-composition table (24). Energy constraints were estimated by using the mean body weights of each age group, and the FAO/WO/UNU algorithms were used to calculate the average energy requirements of breastfed children (25). This would ensure that realistic diets were selected.

In the CF product models, the portion size of CF product was 33 g/d DW for the 6- to 8-mo-olds and was 40 g/d DW for the 9- to 11-mo-olds. These serving sizes were based on the median

TABLE 2
Nutrient composition of the intervention foods per 100 g dry weight[1]

	WF[2]	WF-L	CSB++	CSB+[3]
Energy (kcal)	474	428	458	482
Protein (g)	15.4	12.6	16.8	14.6
Fat (g)	10.3	9.2	10.7	16
Vitamin C (μg)	0.2	100	100	100
Thiamin (mg)	0.2	0.1	0.1	0.1
Riboflavin (mg)	0.1	0.5	0.5	0.5
Niacin (mg)	5.2	4.8	4.8	4.8
Vitamin B-6 (mg)	0.4	1.7	1.7	1.7
Folate (μg)	12	60	60	60
Vitamin B-12 (μg)	2	2	2	2
Vitamin A (μg)	35	166	166	166
Calcium (mg)[4]	570[1]	631[1]	277[1]	173[1]
Total iron (mg)[4]	4.2[1]	6.3[1]	10.5[1]	9.9[1]
Zinc (mg)[4]	4.5[1]	5.2[1]	7.0[1]	6.6[1]

[1] Values for macronutrients and minerals were analyzed in samples of all 4 foods. The energy contents were calculated from macronutrient contents. WF-L, CSB++, and CSB+ were fortified with the same mineral and vitamin mix following the specifications for CSB+ and CSB++ from WFP specifications version 1.1 2010 (14, 15). CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; WF, WinFood; WF-L, WinFood-Lite.

[2] The vitamin values for WF were calculated from food-composition values of 77% rice and 14% fish. The nutrient composition of rice and fish was obtained from the USDA (rice, USDA:50446; fish, USDA15089) (22).

[3] The estimated energy content of CSB+ includes oil distributed to be added at the time of preparation.

[4] Values for calcium, iron, and zinc are analyzed values. WF-L, CSB+, and CSB++ were added mineral premix, which should contribute 130 mg Ca (added as mono- or di-calcium phosphate), 6.5 mg Fe (added as 4.0 mg ferrous fumerate and 2.5 mg iron-sodium EDTA; and 5 mg Zn (added as zinc oxide).

TABLE 3
Foods consumed by 6- to 11-mo-old infants, median serving sizes, and maximum servings per week

	6–8 mo		9–11 mo	
	Serving size[1]	Maximum consumption[2]	Serving size[1]	Maximum consumption[2]
	g/d	*servings/wk*	*g/d*	*servings/wk*
Fruit (snack)				
Plantains, raw	47	5	74	3
Pineapples, raw	5	3	—	—
Limes, raw	—	—	4	1
Papayas, unripe, raw	—	—	6	2
Tamarinds, raw	2	1	2	2
Added fats				
Oil, sunflower	1	7	1	7
Added sugars				
Sugar, white	1	7	1	7
Sugar, brown	1	7	1	7
Staples				
Rice, refined, raw	33	14	55	14
Bakery				
Bread, wheat, refined	22	2	8	1
Animal-source foods				
Eggs, duck, raw	16	1	8	1
Pork, lean, raw	7	6	10	3
Pork, spareribs, raw	18	1	3	1
Chicken, breast meat, raw	3	2	11	4
Beef, lean, raw	—	—	15	1
Large fish I[3]	3	3	6	1
Large fish II[3]	13	4	3	1
Large fish III[3]	—	—	23	3
Shrimp, dried	1	2	1	3
Fermented fish	1	7	1	3
Vegetables				
Cabbage, Chinese, raw	23	4	21	2
Morning glory, raw	11	5	8	4
Tamarind leaves, raw	1	5	1	1
Gourd, sponge, raw	11	2	3	3
Gourd, wax, mixed variety, raw	24	2	6	3
Tomatoes, red, ripe, raw	6	2	—	—
Water lily, stern, raw	—	—	12	3
Onion, fresh, raw	—	—	20	3
Yard long bean, green, raw	—	—	1	2
Snacks				
Candy, jelly pieces	33	1	29	1
Potato chips	7	7	8	3
Human milk[4]	576	7.1	541	7.1
Formulated CF[5] products[6]	33	14	40	14

[1] Values are median serving sizes estimated from the observed intakes of consumers.
[2] The lower limit for number of servings/wk for all food items was 0, except for human milk (6.9 servings/wk) and the intervention products (7 servings/wk).
[3] Large fish species eaten without bones includes a variety of fish species in Cambodia.
[4] The amount of breast milk was estimated from values published by WHO (1998) (3).
[5] CF, complementary food.
[6] Corn-Soy-Blend Plus, Corn-Soy-Blend Plus Plus, WinFood, and WinFood-Lite.

rice serving size for 6- to 8-mo-olds and 72% of the median rice serving size for 9- to 11-mo-olds, assuming that the CF product would replace all rice meals for the younger age group and 75% of the meals for the older age group. The value of 40 g/d DW was chosen based on recommendations on the daily portion size of DW-processed fortified CF for infants aged 6–11 mo (26).

The mean breast-milk intakes for the study population were unknown. Therefore, published average breast milk intakes of 403 kcal/d (576 g/d) and 379 kcal/d (541 g/d) for 6- to 8-mo-olds and 9- to 11-mo-olds, respectively, were entered in all models (3).

The dietary data were prepared in Excel 2010 (Microsoft Corporation). The median portion sizes for consumers, and the percentage of children who consumed each food were calculated in MS Access 2010. The LP models were run by using the WHO Optifood tool v.3.1.1. Anthropometric z scores were calculated based on WHO's 2006 Child Growth Standards (27) with the use of Anthro v.3.1. A child was categorized as wasted, underweight,

TABLE 4
Food-group goals (average serving/wk), food-group constraints (minimum and maximum servings/wk), and food-subgroup constraints (minimum and maximum servings/wk) for the 6- to 8-mo and 9- to 11-mo age groups[1]

	6–8 mo			9–11 mo		
Food group	Minimum consumption	Average consumption[2]	Maximum consumption	Minimum consumption	Average consumption[2]	Maximum consumption
		servings/wk			*servings/wk*	
Added fats	0	0.1	7	0	0.1	7
Added sugars	0	0.1	9	0	7	9
Bakery	0	0.1	2	0	0.1	1
Fruit	0	0.1	7	0	0.1	7
Vitamin C–rich fruit	0	—	5	0	—	6
Other fruit	0	—	4	0	—	2
Vegetables	0	7	9	0	7	14
Vitamin A–source dark-green leafy	—	—	9	—	—	5
Other vegetables	—	—	11	—	—	7
Condiment vegetables	—	—	—	—	—	3
Savory snack	0	0.1	7	0	7	3
Sweetened snacks and desserts	0	0.1	1	0	0.1	1
ASF	0	7	21	0	14	28
Eggs	0	—	1	0	—	1
Fish without bones	0	—	7	0	—	5
Pork	0	—	7	0	—	4
Red meat	0	—		0	—	1
Poultry	0	—	2	0	—	4
Seafood	0	—	2	0	—	3
Small, whole fish, with bones	0	—	7	0	—	3
Human milk	6.9	7	7.1	6.9	7	7.1
Staple (rice)	4	7	14	4	7	14
Snack	0	7	10	0	7	10
Formulated CF products[3]	7	11	14	7	11	14

[1] ASF, animal-source foods; CF, complementary food.
[2] Average serving sizes were based on the observed median number of servings of foods in each food group. Values of 0.1 represent a median of 0. Nonzero values were entered in the models to avoid a division by zero.
[3] Corn-Soy-Blend Plus, Corn-Soy-Blend Plus Plus, WinFood, and WinFood-Lite.

or stunted if his or her z score for weight-for-length, weight-for-age, or length-for-age were less than –2 SD. The population-descriptive statistics were analyzed in Stata 12 for Windows (StataCorp).

RESULTS

Characteristics of respondents

The mean body weight and calculated average energy requirements for the 6- to 8-mo-old (n = 35) and 9- to 11-mo-old (n = 43) infants were 7.5 kg and 578 kcal/d and 8.1 kg and 624 kcal/d, respectively. Overall, 10% of the infants were wasted, 17% were underweight, and 14% were stunted. Only 6% of the mothers had never attended school, 60% had a primary school-level education, and 34% had a junior or senior high school–level education. The main primary source of income in the households was farming, mainly rice crops (60%). All infants, except one were partially breastfed.

Food patterns

Overall, 60 different food items were reported in the dietary recalls collected from both age groups. From the list of 60 foods, 24 food items were included in the LP models for 6- to 8-mo-old infants and 29 food items were included in the models for the 9- to 11-mo-old infants (Table 3). The excluded food items were condiments and rarely consumed food items, which were eaten only once and were not of high nutrient value. The most common foods consumed across the 2 groups were rice (99%), sunflower oil (55%), potato chips (49%), and pork (40%). For the 9- to 11-mo-old infants, different species of large fish without bones and various fermented fish products were also commonly consumed (>35%).

Most infants consumed rice, vegetables, and ASF every day (Table 4). The 9- to 11-mo-old infants also consumed added fats, sugar, and savory snacks on a daily basis and twice as many different types of ASF as the 6- to 8-mo-old infants. Fruit and sweetened snacks or desserts were rarely consumed by any of these infants (Table 4).

Servings sizes

In the 6- to 8-mo-old group, the serving sizes varied from 1 g/d for white sugar to 47 g/d for plantain, but most foods (n = 17; 71%) had serving sizes <15 g/d. In the 9- to 11-mo-old group, the serving sizes varied from 1 g/d for white sugar to 74 g/d for plantain, and again, most of the foods (n = 24; 80%) had serving sizes <15 g/d (Table 3).

TABLE 5
Number of servings per week by food group in the best diet for the baseline diet and each diet with a CF product[1]

	6–8 mo					9–11 mo				
	Baseline	WF	WF-L	CSB++	CSB+	Baseline	WF	WF-L	CSB++	CSB+
	servings/wk					*servings/wk*				
Fruit	7	3	3	0	3	7	5	5	3	5
Added sugars	0	0	0	0	0	0	0	0	0	0
Vegetable	9	9	9	9	9	14	14	14	14	14
Savory snacks	7	0	0	0	0	3	0	0	0	0
Bakery and breakfast cereals	2	0	0	0	0	1	1	1	0	0
Meat, fish, and eggs	21	21	21	20	21	21	16	11	12	15
Grains and grain products	4	0	0	0	0	5	0	0	0	0
Human milk	7	7	7	7	7	7	7	7	7	7
Formulated CF products[2]	—	7	8	8	7	—	8	9	8	8

[1] The "best diet" was the diet that came as close as possible to meeting the nutrient Recommended Nutrient Intake goals for protein, vitamin C, thiamin, riboflavin, niacin, vitamin B-6, folate, vitamin A, calcium, iron, and zinc while respecting modeled energy and food-pattern constraints. CF, complementary food; CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; WF, WinFood; WF-L, WinFood-Lite.
[2] WF, WF-L, CSB++, and CSB+.

The food pattern of the optimal modeled diet

A total of 16 food items were selected in the nutritionally optimal baseline diet for the 6- to 8-mo-old group, and 22 food items were selected in this diet for the 9- to 11-mo-old infants. The number of servings selected of ASF, vegetables, fruit, and bakery products exceeded the median number observed for these 2 populations (Table 4 and **Table 5**), whereas fewer than the median numbers of servings of rice were selected. The number of servings of savory snacks selected, in the nutritionally optimal diet, was above the median number observed for the 6- to 8-mo-old but below this number observed for the 9- to 11-mo-old (Tables 4 and 5). When the special complementary feeding products were included in the models, in the optimal diets the number of servings/wk of fruit for both age groups and of ASF for the 9- to 11-mo-old group declined; for both age groups, the special complementary feeding products replaced rice in the diets. Between 7 and 9 servings/wk of these formulated CF products were selected in each optimal modeled diet across both groups (Table 5).

Nutrients

Vitamins A, B-6, and C were the only nutrients that, in the nutritionally optimal baseline diet, met their daily nutrient requirements (19) in both age groups. Without special complementary feeding products, all other micronutrients were problem nutrients. The highest levels achieved (ie, best-case scenario levels) for these micronutrients ranged from 14% (iron) to 93% (vitamin B-12) of their RNIs (**Table 6**). The formulated complementary feeding products increased the number of micronutrients that achieved recommended levels in the optimal diets from 4 micronutrients at baseline to 6 (WF and CSB+) or 7 (WF-L and CSB++) of the 11 micronutrients modeled, for the 6- to 8-mo-old and to 7 (WF), 8 (CSB+ and CSB++), or 9 (WF-L) of the 11 micronutrients modeled for the 9- to 11-mo-olds. Iron, thiamin, and folate remained below the RNI in all modeled diets, ie, remained "problem nutrients." However, for other nutrients, the results suggest that daily consumption of the special CF products would ensure that the daily requirements were met for vitamin A, vitamin C, vitamin B-12, vitamin B-6, riboflavin (except WF), niacin, calcium (except CSB+), and zinc by using the criteria of achievement of >65% RNI in the worst-case scenario (Table 6 and **Table 7**).

DISCUSSION

We showed how LP can be used to investigate whether 4 different CF products could contribute to filling nutrient gaps in the local diets of 6- to 11-mo-old Cambodian infants and thereby help ensure dietary adequacy. The LP modeling indicated that the products provided in realistic servings would improve the nutritional quality of the diet but not ensure adequate intakes of all micronutrients. Iron, thiamin, and folate remained problem nutrients in all modeled diets. They also suggest that WF-L and CSB ++ are slightly superior to WF and CSB+ at ensuring dietary adequacy, because they ensured >65% of the daily requirement for 8 of 11 micronutrient, whereas WF and CSB+ ensured dietary adequacy for 7 of 11 micronutrients. These findings highlight the value of modeling specific CF products, when planning a nutrition intervention, to determine whether they are likely to meet nutritional requirements for multiple micronutrients in a target population's diet.

The modeled optimal baseline diets clearly suggest that, for any improved CF product, it would be a challenge to cover the nutrient gaps. The nutrient contents of even the nutritionally best diets, for these specific populations, were low for a range of nutrients. These results agree with those of a previous dietary survey done in villages on the outskirts of Phnom Penh, which showed that calcium, iron, and zinc were consistently below the RNI (28).

Remarkably, vitamin A was not identified as a problem nutrient for this particular population. The baseline diet in both age groups would ensure >81% of the required vitamin A intake in the worst-case scenario, which increased to >98% when the diets included WF-L, CSB++, or CSB+. One of the main food sources of vitamin A in these modeled diets was breast milk, which was included in every modeled diet in a specified amount. The results for vitamin A will therefore depend on maternal vitamin A status, because it will influence breast-milk vitamin A concentrations (29). Furthermore, actual breast-milk concentrations

TABLE 6

The optimal, best-case scenario, and worst-case scenario diets for each nutrient expressed as a percentage of their recommendations (Recommended Nutrient Intakes) for the baseline diet and each diet with the formulated food products in 6- to 8-mo-old infants[1]

	Protein[2]	Vitamin C[3]	Thiamin[3]	Riboflavin[3]	Vitamin B-3[3]	Vitamin B-6[3]	Folate[3]	Vitamin B-12[3]	Vitamin A[3]	Calcium[3]	Iron[4]	Zinc[5]
Baseline, optimal diet[6]	141	135	69	80	64	103	69	91	140	52	14	48
Best-case scenario[7]	147	149	71	80	66	111	71	93	144	57	14	50
Worst-case scenario[8]	95	97	36	57	42	42	41	41	87	47	6	39
WF, optimal diet[6]	168	133	74	74	86	94	55	183	121	100	22	73
Best-case scenario[7]	170	148	77	75	88	102	60	193	140	107	24	73
Worst-case scenario[8]	127	97	48	59	69	67	41	140	90	93	17	66
WF-L, optimal diet[6]	161	223	67	106	86	257	80	191	148	102	33	84
Best-case scenario[7]	165	257	73	109	88	276	83	199	155	109	34	86
Worst-case scenario[8]	118	164	42	89	66	210	61	135	100	90	25	72
CSB++, optimal diet[6]	175	227	65	103	83	245	78	185	147	77	47	97
Best-case scenario[7]	178	259	71	106	86	260	81	191	152	80	50	100
Worst-case scenario[8]	133	164	41	89	66	210	61	135	100	69	40	86
CSB+, optimal diet[6]	163	211	65	101	81	234	77	179	146	67	43	90
Best-case scenario[7]	165	243	69	104	83	248	79	186	151	70	45	93
Worst-case scenario[8]	124	164	41	87	65	209	61	135	100	60	37	83

[1] CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; WF, WinFood; WF-L, WinFood-Lite.
[2] WHO/FAO/UNU protein and amino acid requirements in human nutrition (20).
[3] FAO/WHO-recommended nutrient intake (19).
[4] FAO/WHO-recommended nutrient intake, assuming 10% absorption (19).
[5] IZiNCg, assuming moderate absorption (21).
[6] The optimal diet formulated by using goal programming (Optifood Module II).
[7] Each diet sequentially maximizes each micronutrient (Optifood Module III; "best-case scenario").
[8] Each diet sequentially minimizes each micronutrient (Optifood Module III; "worst-case scenario").

were not measured in this study. An overestimation of average breast milk intakes would affect these estimates of dietary vitamin A adequacy. For these reasons, the results for vitamin A should be interpreted with caution, particularly given some evidence of vitamin A deficiency in the country (30), although the recent national data for vitamin A status is lacking. The other important food source of vitamin A was morning glory. Morning glory is a commonly consumed green leafy vegetable in Cambodia. Traditional CF made from food items rich in vitamin A is reported to be moderately high in Cambodia (12), which would

TABLE 7

The optimal, best-case scenario, and worst-case scenario diets for each nutrient expressed as a percentage of their recommendations (Recommended Nutrient Intakes) for the baseline diet and each diet with the formulated food products in 9- to 11-mo-old infants[1]

	Protein[2]	Vitamin-C[3]	Thiamin[3]	Riboflavin[3]	Vitamin B-3[3]	Vitamin B-6[3]	Folate[3]	Vitamin B-12[3]	Vitamin A[3]	Calcium[3]	Iron[4]	Zinc[5]
Baseline, optimal diet[6]	154	138	64	75	83	118	71	89	135	52	14	51
Best-case scenario[7]	159	143	64	76	84	119	72	89	144	53	14	54
Worst-case scenario[8]	98	97	39	56	47	48	40	39	81	44	7	42
WF, optimal diet[6]	178	137	76	73	101	108	62	220	136	114	28	86
Best-case scenario[7]	190	143	77	75	117	136	69	228	147	121	29	88
Worst-case scenario[8]	130	97	52	58	78	77	40	158	85	100	21	72
WF-L, optimal diet[6]	170	247	68	118	102	335	93	225	153	117	42	101
Best-case scenario[7]	183	270	70	120	117	356	96	235	162	123	44	104
Worst-case scenario[8]	120	164	45	95	76	252	65	153	98	96	30	80
CSB++, optimal diet[6]	188	252	66	114	100	321	90	217	144	83	61	119
Best-case scenario[7]	200	271	67	116	113	334	94	225	161	84	65	123
Worst-case scenario[8]	136	163	44	94	75	250	64	153	98	71	48	97
CSB+, optimal diet[6]	176	239	65	111	100	305	88	209	143	69	55	109
Best-case scenario[7]	185	254	68	114	111	319	92	218	160	70	59	113
Worst-case scenario[8]	126	164	44	94	74	249	64	153	98	60	45	93

[1] CSB+, Corn-Soy-Blend Plus; CSB++, Corn-Soy-Blend Plus Plus; WF, WinFood; WF-L, WinFood-Lite.
[2] WHO/FAO/UNU protein and amino acid requirements in human nutrition (20).
[3] FAO/WHO-recommended nutrient intake (19).
[4] FAO/WHO-recommended nutrient intake, assuming 10% absorption (19).
[5] International Zinc Nutrition Consultative Group, assuming moderate absorption (21).
[6] The optimal diet formulated by using goal programming (Optifood Module II).
[7] Each diet sequentially maximizes each micronutrient (Optifood Module III; "best-case scenario").
[8] Each diet sequentially minimizes each micronutrient (Optifood Module III; "worst-case scenario").

agree with the model results suggesting that vitamin A intakes were adequate.

Iron was identified as a key problem nutrient in all modeled diets. For the 4 CF products evaluated, total iron contributed from the modeled diets reached <50% of the desired levels, even in the best-case scenario analyses. CSB++ achieved the highest dietary iron contents and WF the lowest dietary iron contents. These findings support the results from the WinFood intervention trial. After a 9-mo intervention period in which children were randomly assigned to be fed 1 of the 4 CF products, both their hemoglobin and ferritin concentrations declined from baseline to endpoint for all groups (13). The prevalence of anemia was highest in the group that had received WF compared with the other CF product groups (data not published). The Cambodian DHS 2010 reported that 55% of children younger than 5 y were anemic (12). Even though the high prevalence of anemia might be partially attributable to parasitic infections or endemic occurrence of genetic hemoglobin disorders (31), our modeling results suggest that low dietary intakes are a contributing factor, despite the use of iron-fortified CF products. Other intervention strategies, such as the use of micronutrient powder (32–34), might be needed to eliminate iron deficiency and anemia.

WF and WF-L ensured adequate dietary nutrient intakes of calcium in both age groups. WF and WF-L contain whole small fish. Whole small fish, for which the bones are edible, has proven to be a good calcium source with a calcium bioavailability similar to that of milk (35). CSB++ contains dried skim milk powder, but its calcium content is half the amount of the 2 WinFood products. In a highly productive aquatic environment, such as Cambodia (36), infants should frequently consume fish. However, in our study, infants were served large fish rather than small fish, so they did not consume calcium-rich bones. Perhaps caregivers are afraid that a fish bone will get stuck in the throat of infants. The advantage of the processed WinFood products was that small fish species were ground, which makes them an acceptable dietary source of calcium for infants. Note that the RNI for calcium, primarily based on studies in whites, has been argued to be too high for ethic Asian populations (37); therefore, the results from Optifood could overestimate the calcium as a problem nutrient in the current population.

The results showed that the CSB products and the WF-L ensured adequate dietary intakes of zinc in the 9- to 11-mo-old group. Zinc is characterized as a growth nutrient (type II nutrient) (38) and is vital for nearly all biochemical pathways in the human body. Therefore, deficient intakes of any of these type-II nutrients will impair child growth (38). Meat and other ASF are the best source of bioavailable zinc. Studies have shown that increased meat consumption is associated with a lower risk of stunting and improves cognitive development and general health (39–41)—an association that is partly a result of an improved intake of bioavailable zinc. The population in the current study consumed ASF (mainly large fish and pork) frequently, but in very small amounts. WF-L and the CSB products are all fortified products. The current results indicate that access to fortified CF products may be needed in this population to achieve sufficient zinc intake.

The extent of the deficit in multiple micronutrients in the modeled baseline diets is large and difficult to meet with a single intervention product. Making formulated nutritionally improved CF products available will contribute to improving overall dietary quality; however, to eliminate undernutrition and poor health, these products should be integrated with approaches that encourage changes to the traditional dietary practices for infants and young children. Before promoting improved CF products and realistic changes to dietary practices, they should be evaluated by using approaches such as the Trial of Improved Practices (42) or Integrated Management of Childhood Illness (43). LP modeling in combination with other approaches can support the development and promotion of realistic interventions to improve dietary adequacy when nutrient gaps are too wide to be covered by food supplementation.

The Optifood LP approach is a potentially powerful instrument for predicting the impact of a nutritional intervention on dietary adequacy. However, this study had several limitations. First, the sample size for the dietary data was small, so rarely consumed nutrient-dense foods might have been missed. In addition, the portion sizes of some foods were estimated from <5 individuals. Second, the dietary data were collected by using average recipes of mixed-food dishes. The mixed dishes in Cambodia contain many different ingredients, and it is difficult to assess exactly which parts of the mixed dishes the infants consumed. Third, the nutrient composition of the modeled food items was obtained from different food-composition databases (22–24). There is considerable variability in the nutrient content of foods related to local conditions, such as soil, cultivation, and food processing (11), which might have introduced errors. Fourth, most of the RNIs are based on Adequate Intake estimates, except for iron and zinc, which are based on Recommend Dietary Allowances. Adequate Intakes are based on intakes of a healthy population and therefore might overestimate the actual nutrient needs (11). To address this potential source of error, we selected a more conservative criterion, 65% of the RNI, for comparing the baseline diets and special CF products. These limitations are important to take into account when interpreting results from diet modeling.

These findings emphasize the value of nutrition program planners using LP to evaluate special CF products during the intervention planning phase. With the LP approach, we were able to make a distinction across the 4 formulated CF products in terms of their potential for ensuring dietary adequacy of selected micronutrients for the target groups. Such information is valuable for planning a nutritional-intervention program or for understanding the reasons for an unexpected lack of response to a program.

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