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Original Article

Zinc, iron and calcium are major limiting nutrients in the complementary diets of rural Kenyan children

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Abstract

Poor quality infant and young child (IYC) diets contribute to chronic under-nutrition. To design effective IYC nutrition interventions, an understanding of the extent to which realistic food-based strategies can improve dietary adequacy is required. We collected 24-h dietary recalls from children 6–23 months of age ($n = 401$) in two rural agro-ecological zones of Kenya to assess the nutrient adequacy of their diets. Linear programming analysis (LPA) was used to identify realistic food-based recommendations (FBRs) and to determine the extent to which they could ensure intake adequacy for 12 nutrients. Mean nutrient densities of the IYC diets were below the desired level for four to nine of the 10 nutrients analysed, depending on the age group. Mean dietary diversity scores ranged from 2.1 ± 1.0 among children 6–8 months old in Kitui County to 3.7 ± 1.1 food groups among children 12–23 months old in Vihiga County. LPA confirmed that dietary adequacy for iron, zinc and calcium will be difficult to ensure using only local foods as consumed. FBRs for breastfed children that promote the daily consumption of cows'/goats' milk (added to porridges), fortified cereals, green leafy vegetables, legumes, and meat, fish or eggs, 3–5 times per week can ensure dietary adequacy for nine and seven of 12 nutrients for children 6–11 and 12–23 months old, respectively. For these rural Kenyan children, even though dietary adequacy could be improved via realistic changes in habitual food consumption practices, alternative interventions are needed to ensure dietary adequacy at the population level.

Keywords: dietary recommendations, infants, Kenya, linear programming, nutrition, young children.

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Introduction

Micronutrient deficiencies continue to be prevalent among children in low-income countries, and they contribute to the global burden of disease, impaired child development and stunted growth (Black et al. 2013). Poor quality infant and young child (IYC) diets partially account for these micronutrient deficiencies, underscoring the importance of identifying ways to improve diet quality. In response, a global strategy was recently put forth to support caregivers in improving the nutritional quality of IYC diets by promoting the use of suitable, locally available foods, including fortified foods (World Health Organisation [WHO]/UNICEF 2003). These guidelines, however, are not context specific. As a result, adaptations to local circumstances are required to focus on locally available, affordable and acceptable nutrient-dense foods.

To create evidence-based dietary recommendations for specific populations, information on the current dietary sources of nutrients, food intake patterns and gaps in achievement of nutrient intake requirements are required (Dewey & Brown 2003). LPA is a useful technique for identifying locally appropriate, low-cost food-based recommendations (FBRs) to fill nutrient intake gaps through behaviour change and other interventions. It can also be used to identify nutrients for which gaps cannot be realistically filled, using local foods as consumed, and for which alternative solutions are required (Ferguson et al. 2006).

In Kenya, indicators of IYC feeding practices and nutritional adequacy suggest that low-quality IYC diets are common (Kenya National Bureau of Statistics [KNBS] & ICF Macro 2010). For example, 42% of children 6–23 months of age received complementary foods from no more than two food groups, representing a level of food diversity associated with a high risk of inadequate nutrient intakes (WHO et al. 2008), and 33% did not meet the minimum recommended feeding frequency (KNBS & ICF Macro 2010). Nearly half of Kenyan children also experience linear growth stunting, a key indicator of chronic malnutrition, which rises rapidly from infancy through the second year of life (KNBS & ICF Macro 2010). This evidence suggests a general need to improve the quality of IYC diets. However, region-specific FBRs may be required in Kenya, given the wide range of agro-ecologies and demographic and cultural influences that affect the availability of foods and their use in IYC diets.

As part of a research programme to determine the potential of local foods to improve the nutrient quality of IYC diets, and identify possible intervention points requiring support to increase accessibility of foods identified in the FBRs, the specific objectives of the current study were to: (1) quantify food and nutrient intakes in the complementary diets of rural Kenyan children 6–23 months of age in relation to recommendations; (2) identify an initial set of locally appropriate, low-cost FBRs to improve the adequacy of nutrient intakes of these children; and (3) identify nutrient gaps that cannot be filled using local foods as consumed. This research was carried out in two distinct food-insecure regions of Kenya.

Materials and methods

Study populations

Two food-insecure counties were selected to represent distinct agro-ecological zones in Kenya. Kitui County represents a sparsely populated (33 people per sq km), semi-arid area, while Vihiga County represents a densely populated (1045 people per sq km), high-rainfall area (Commission on Revenue Allocation [CRA] 2011). Both counties are characterised by high rates of stunting among children under 5 years of age (42% and 34%, respectively) (KNBS & ICF Macro 2010), and large numbers of impoverished households (CRA 2011).

Survey design

A cross-sectional survey of children 6–23 months old was conducted in four districts of Vihiga County during a season of relatively high food diversity (August 2012) and in four districts of Kitui County at the end of the food shortage season (October/November 2012). Dietary intake, anthropometric and socio-demographic data (interviewer administered questionnaire) were collected by 10 trained, experienced research assistants. The survey was approved by the Ethics Committee of the National Council for Science and Technology (Nairobi), and analysis of the collected data was approved by the Ethics Committee of the London School of Hygiene and Tropical Medicine (London). Informed, signed consent to participate was obtained from all participants.

Sampling

Stratified (by age sub-group) random sampling was used to select children from the four purposively selected districts in Vihiga County (Luanda, Emuhaya, East Tiriki and West Tiriki; $n = 201$) and Kitui County (Kitui Central, Lower Yatta, Mutomo and Kitui West; $n = 200$). The four age sub-group strata included

Key messages

- The dietary intakes of rural 6–23-month-old children living in two distinct agro-ecological zones in southern Kenya did not achieve WHO desired levels for four to nine micronutrients, depending on the age group and county
- A food-based intervention promoting locally available foods as currently consumed can be used to ensure dietary adequacy for all nutrients except iron, zinc and calcium (in one county) for children 6–23 months old living in two distinct agro-ecological zones in southern Kenya.
- Affordable, culturally acceptable alternative interventions are required for rural children 6–23 months old in eastern and western Kenya to ensure adequate dietary intakes of iron, zinc and, in some cases, calcium.

children 6–8, 9–11, 12–17 and 18–23 months of age. The inclusion criteria were that a child was 6–23 months of age inclusive and that his or her primary caregiver was available for, and agreed to participate in, the survey. If more than one child in a household met the inclusion criteria, then one was randomly selected.

Dietary assessment

Dietary intakes were estimated using a four-pass 24-h dietary recall (24-HR), adapted from Gibson & Ferguson (2008). All days of the week were represented to avoid any related effects on dietary intakes. Portion sizes were measured either as direct weights of real foods on dietary scales or as volumes that were later converted to grams. Standard average recipe data for common composite dishes were collected from ≥10 caregivers per recipe in the study areas (Gibson & Ferguson 2008). For other composite dishes, ingredient amounts were determined at the household level by estimating the weight of raw ingredients as a proportion of the total cooked dish eaten.

Anthropometric assessment

Body weight was measured in duplicate using a digital scale (Seca model 770; precision ± 0.1 kg), and the mean was calculated. Weight-for-age z-scores and prevalence of underweight children (z-score <-2) were calculated (WHO 2006a).

Market survey

For each food item reported in the 24-HRs, retail price data were collected from at least five different selling locations in each county, including roadside vendors, kiosks, open markets and supermarkets. The price (Kenyan Shillings) per 100-g edible portion was calculated.

Data processing and descriptive analyses

Data entry, processing, cleaning and descriptive and statistical analyses were done using MS Excel 2007 and Stata version 10.1. Data from the 12–17 and 18–23 months of age sub-groups were combined for all analyses. Dietary diversity scores were calculated for each breastfed child by counting the number of food groups reported in the 24-HR using the seven food groups defined by WHO (WHO et al. 2008).

Energy and nutrient intakes from all foods and beverages were calculated using a food composition database compiled for this survey, following established methods (Hotz et al. 2011). For fortified food products, local product label information on nutrient content was used. Nutrient densities for the complementary feeding diets were calculated for each participant and compared with WHO-desired levels (Dewey & Brown 2003).

Linear programming analysis

LPA was used to generate a series of optimised modelled diets that identified: (1) problem nutrients (i.e. nutrients likely to remain low in IYC diets based on local food sources, as consumed); (2) the best available food sources to fill nutrient gaps; and (3) alternative FBRs for 7-day diets that would improve dietary adequacy for 11 micronutrients (calcium, iron, zinc, riboflavin, niacin, thiamine and folate, and vitamins A, B6, B12 and C). All analyses were done using Optifood software (Daelmans et al. 2013). The mathematical models used in this approach and general model constraints were previously described in detail (Ferguson et al. 2006; Daelmans et al. 2013). The main steps of analysis undertaken in the present study are described below.

The constraints used in all analyses to ensure that modelled diets were realistic were: (1) the energy [kilocalorie (kcal)] content of each modelled diet, which was equal to the average energy requirement for the sub-group; (2) the minimum and maximum (generally corresponding to the 10th and 90th percentiles, respectively) number of servings from food groups and food sub-groups per week; and (3) the grams of each individual food item per week. These week-based parameters were estimated using individual 24-HRs multiplied by 7 to simulate weekly food intakes. Median serving sizes were determined for all food items (g/meal) for consumers in each age group and county. Two methods were used to estimate daily breast milk intakes, and the results (Module I analyses) were compared. In one method, published average breast milk intakes for children in developing country regions were used (WHO 1998). In the other method, breast milk intakes were estimated for each age and county sub-group as the difference between average energy requirements (kcal/day) and the median energy content of the complementary diet. Breast milk was assumed to contain 65 kcal/100 g [Institute of Medicine (IOM) 1991]; energy requirements were estimated based on age, body weight (in kg) and breastfeeding status [Food and Agriculture Organization of the United Nations (FAO)/WHO/United Nations University (UNU) 2004] and median energy intakes from the complementary diet were derived from the 24-HR data. Of these two methods, the last named was used unless it generated unrealistic Module 1 modelled diets. Specifically, if the numbers of food items selected in each of the 19 Module I modelled diets were either all below or all above the observed range in number of food items, then the quantity of breast milk modelled was deemed unrealistic.

The list of foods included in each modelled diet consisted of all food items consumed by ≥5% of the children surveyed for each age group and county and some less frequently consumed food items, if they were nutrient dense. Mangos were removed because they are seasonal items and infant formula was removed because it should not be recommended for breastfed children. Nutrient-rich foods, such as eggs, small dried fish and fortified cereal mixes, were added to the list for some age groups, if they were reported to be consumed by another age group in the same county. For infrequently consumed foods, the potential error in estimated median serving sizes was reduced by imputing data from similar food types (e.g. foods from within the same food group or food sub-group from green leafy vegetables, roots, cereal flours, soups, beans, eggs or small fish) within an age group and, if necessary, across age groups. Identical serving sizes were used for all similar food items within selected food subgroups to avoid biassing the selection of specific food items (e.g. one particular type of green leafy vegetable) towards the selection of larger or smaller serving sizes reported for those specific food items.

For the LPA, Optifood's Modules I to III were run (Daelmans et al. 2013) for each age group and county (i.e. six target groups). Details of the objective functions and constraints used in the LPA models are described in Supplementary Appendix Table S1. In brief, Module I was run to check model parameters and to make decisions about which of the two alternative breast milk serving sizes would be used in the analyses. In this module, 19 simulated 7-day diets were generated based on the model parameters and reviewed to determine if they were realistic. If any of these diets was not realistic, adjustments to the model parameters were made by modifying one or more of the constraint levels or the daily breast milk serving size.

In the Module II analysis, a 7-day diet was modelled that came as close as mathematically possible to achieving ≥100% of the WHO/FAO Recommended Nutrient Intakes (RNIs) (WHO 2006b) for the 12 nutrients of interest. This is referred to as the Module II 'nutritionally best diet'. The bioavailabilities of iron and zinc were assumed to be low (5% and 15%, respectively) (WHO 2006b), consistent with diets based on unrefined cereal grains and low amounts of animal-flesh foods. The results from this modelled diet were used to formulate alternative individual FBRs for testing in the Module III analyses and to identify the problem nutrients, as described below.

In the Module III analyses, 24 modelled 7-day diets were generated. For 12 of these diets, the objective functions maximised 1 of the 12 nutrients of interest; for the other 12 diets, the objective functions minimised 1 of the 12 nutrients of interest. The maximised diets were used to define the problem nutrients, and the minimised diets were used to test alternative sets of FBRs, as described below. Module III was initially run without testing an FBR to define the problem nutrients and the baseline minimised nutrient levels (i.e. the minimised nutrient levels without FBRs). In all subsequent Module III analyses, constraints were introduced to ensure each modelled diet achieved the FBR or set of FBRs being tested.

Identifying problem nutrients

Problem nutrients were defined as those nutrients <100% of the RNI in the Module II nutritionally best diet and <100% of the RNI in the Module III maximised diets modelled without FBR constraints.

Selection of FBRs

Individual FBRs selected for screening in Module III were identified in two ways: (1) foods from food groups that had a higher number of servings in the Module II nutritionally best diet than the median observed for those food groups (i.e. food group patterns that have nutritional benefits) and (2) individual food items that provided ≥5% of the nutrient content for at least five micronutrients in the Module II nutritionally best diet (i.e. the best food sources of nutrients) generally expressed at their food sub-group level. For some food groups, the screened FBRs included different recommended frequencies of consumption per week to assess the nutritional or cost implications of recommending different frequencies. These criteria identified the most promising individual FBRs for improving dietary adequacy. A final check, however, was done at the end of the Module III analyses in which the Module II's best food sources of nutrients that remained <70% of the RNI were examined. Additional FBRs were tested, in Module III, if promising food sources of these nutrients were identified.

Testing FBRs

The individual FBRs were first screened in Module III (minimised 7-day diets) to select a sub-set of up to eight individual FBRs for a systematic analysis. Eight is the maximum number of FBRs that can be systematically tested in Optifood. To select this sub-set, the Module III minimised nutrient values of all FBRs screened were compared to identify a combination of FBRs that would likely provide optimal levels of all 12 nutrients modelled. In the systematic analysis, all possible combinations of these selected FBRs were tested. For example, if three FBRs had been selected (i.e. A, B and C) for a systematic analysis, then four different sets of FBRs would have been tested (A–B, A–C, B–C, A–B–C), whereas when eight individual FBRs were selected, then 247 different sets of FBRs were tested. In these series of analyses, population-level dietary adequacy for a nutrient was defined as a minimised 7-day diet value ≥70% of its RNI. This value was selected because a low percentage of the population would be at risk of inadequate intakes, for a nutrient, when its lowest value, in its population intake distribution, was at 70% of its RNI based on the EAR cut-point method for estimating the prevalence at risk of inadequate nutrient intakes at the population level (De Lauzaon et al. 2004). To select the best set of FBRs for a given target group, the minimised 7-day diet nutrient values for all sets of combined individual FBRs tested were compared, and the set(s) of FBRs that had the highest number ≥70% of its RNI for the lowest number of FBRs per set and lowest cost was selected. Finally, the best sets of FBRs were compared across each age group within a county to select a relatively consistent set of FBRs to promote across all age groups. *Sensitivity analyses:* Sensitivity analyses were done to determine whether the results for problem nutrients were sensitive to the iron and zinc RNIs used. Module II and Module III maximised objective functions analyses were re-run using the WHO/FAO RNIs for iron and zinc, assuming 10% absorption for iron and moderate bio-availability for zinc, and using the International Zinc Nutrition Consultative Group (IZiNCG) RNI for zinc, assuming low bio-availability (Hotz & Brown 2004).

Results

Survey results

Household data are presented for 201 and 200 children from Vihiga and Kitui Counties, respectively. The dietary-based analyses used data for 156 children in Vihiga and 179 children in Kitui. The reasons for excluding data were that (1) the children were no longer breastfeeding ($n = 43$ and $n = 20$ in Vihiga and Kitui, respectively) and (2) children had implausible energy intakes ($n = 2$ and $n = 1$ in Vihiga and Kitui, respectively).

Children from both counties were predominantly from low-income farming families that owned a limited number of assets, living on 1 acre of land or less and accessing water from rivers or communal water sources (Table 1). Few caregivers had completed secondary or higher levels of education. The primary sources of household income were from casual labour, in both counties. Own business and the selling of agricultural produce were more important sources of household income in Vihiga than in Kitui.

Table 1. Characteristics of participating breastfed children 6–23 months of age in Kitui and Vihiga Districts, Kenya, and socio-economic characteristics of their households

	Kitui $n = 179$ %	Vihiga $n = 156$ %
Low-income (≤8000 KSh/ month)	78.0	77.1
Self-owned land	93.5	96.5
Land size ≤ 1 acre	46.0	86.0
Household source of water		
River	51.5	81.6
Communal well/pump/tap	41.5	12.9
Other	7.0	5.5
Maternal education		
None	3.5	4.0
Standard	86.0	86.6
Secondary or tertiary	10.5	9.5
Household sources of income*		
Casual labour	45.0	48.8
Business	16.5	37.3
Formal employment	10.5	10.0
Agricultural produce	3.5	22.4
Other	4.5	8.0
Weight-for-age z-score < −2		
6–8 months	12.2	4.4
9–11 months	18.8	12.1
12–23 months	8.2	6.4

*Multiple income sources could be reported.

The number of unique food items consumed ranged from 35 among children 9–11 months old in Kitui to 59 among children 12–23 months old in Vihiga. Across all age groups, 60 unique food items were consumed in Kitui and 69 in Vihiga. However, only 8–13 food items were consumed by ≥20% of the children (Table 2). The majority of children in both counties consumed porridges based primarily on unrefined maize flour and secondarily on millet or sorghum flour. The most important accompaniment to staples in Vihiga was green leaf stew (e.g. kale leaves), while in Kitui, it was the broth from vegetable stews. Milk was consumed by many children (85% of children in Vihiga and 53% in Kitui), while few children consumed animal-flesh foods (0%–2% in Kitui and 11%–27% in Vihiga) and fresh fruits (8%–9% in Kitui and 6%–13% in Vihiga). The limited numbers of commonly consumed foods was reflected in the dietary diversity scores, which were both lower in Kitui than in Vihiga (Table 2).

Of the 60 and 69 foods consumed in Kitui and Vihiga, respectively, 55 and 60 foods, respectively, were included in the models. In Kitui, the rarely consumed foods that were excluded were infant formula, a brand of vegetable oil, mango, mandazi and a brand of fortified mixed flour. Some brands of vegetable oil and fortified flour were included in the models because they were consumed by more children than those excluded. In Vihiga, the rarely consumed foods that were excluded were a brand of vegetable oil, mango, cassava flour, arrow root, fried potato chips, sweet biscuits, chapatti, boiled maize and refine white maize flour. These foods were consumed by less than 2 of the 201 children, except for cassava flour (five children) and the oil (four children). Different brands of vegetable oil, roasted maize and other roots were included in the models because they were consumed by more children than those excluded.

The nutrient densities of the IYC diets for children 6–8 months old were below WHO-desired levels for all nutrients except vitamin A and vitamin C (Kitui only); for the other age groups, they were below desired levels for seven of the 10 nutrients in Kitui and from four to six of the 10 nutrients in Vihiga (Table 3).

Linear programming analyses results

Problem nutrients

In Kitui, the problem nutrients were iron and zinc in all age groups, and vitamin B12 in the 12–23 month age group (Table 4). In Vihiga, calcium, iron and zinc were problem nutrients in all age groups. Niacin may be excluded as a problem nutrient among children 6–8 months old (i.e. maximised value of 98% RNI) because tryptophan will contribute to the overall dietary intakes of niacin.

Selection of FBRs for screening

In both Kitui and Vihiga, the most important food sources of nutrients in the Module II nutritionally best diet were ‘Unger’ and ‘Proctor & Allan’ brand fortified mixed cereal flours, fortified ‘Weetabix’ cereal, maize flour, millet flour, cow’s milk and kale. In Kitui, kidney beans, arrow root, vegetable broth, kale and spinach were also important food sources of nutrients, while

Table 2. Dietary diversity and percentage of breastfed children in Kitui and Vihiga consuming common food items

Food item	Kitui			Vihiga		
	6–8 months	9–11 months	12–23 months	6–8 months	9–11 months	12–23 months
n	49	32	98	45	33	78
Dietary diversity score, mean ± SD	2.1 ± 1.0	2.6 ± 1.0	2.4 ± 1.1	3.0 ± 1.1	3.5 ± 0.9	3.7 ± 1.1
% ≥4 food groups	6.1	21.9	20.4	42.2	60.6	62.8
Unique food items consumed, *n*	36	35	54	46	48	59
Food items consumed by ≥20%, *n*	8	13	11	11	8	10
		%			%	
Maize flour, unrefined	57	63	81	89	91	95
Maize flour, refined	16	38	17	2	3	—
Millet flour	31	22	20	9	18	14
Sorghum flour	24	25	24	13	18	12
Rice	14	31	29	1	15	22
Potato	12	41	16	24	24	18
African donut	—	—	2	2	18	31
Milk, cow, fresh	55	28	28	89	79	85
Milk, goat, fresh	20	16	18	—	—	—
Kale leaves	—	9	8	20	30	40
Tomato	18	63	51	36	67	68
Avocado	8	3	—	20	9	14
Onion	14	50	47	36	70	65
Kidney beans	10	22	18	—	—	—
Broth, chicken	2	—	1	42	—	—
Broth, vegetable	31	53	47	18	15	10
Tea, brewed	—	3	7	42	54	78
Sugar	59	66	62	91	79	95
Vegetable oil	6	16	7	60	70	72
Margarine	27	28	22	9	3	5
Vegetable fat, white	12	38	45	9	18	17

in Vihiga, small fish (*omena*) were important. For at least one target group, these foods contributed ≥5% of the diet's nutrient content for at least five nutrients. The food groups that had a higher number of servings per week in the Module II nutritionally best diet than in the observed diets (medians) in both Kitui and Vihiga were fortified cereal products; legumes; dairy products; meat, fish or eggs (MFE); fruits (only for children 12–23 months old in Kitui); and vegetables. In Kitui, the number of servings of broths and starchy roots and plant foods was also higher in the Module II nutritionally best diets than in the observed diets.

Depending on the age group, between 11 and 15 individual FBRs were screened in the Module III analyses (Table 5). Although unrefined maize flour was an important food source of nutrients for all age groups in both counties, it was not screened because most children consumed it, and, thus, it was included in all modelled diets via a lower bound constraint (i.e. maize flour ≥7 servings per week).

Selection of final sets of FBRs

After screening the individual FBRs, from five to eight individual FBRs were selected for a systematic analysis, because the results indicated a combination of these FBRs would contribute to dietary adequacy. From this analysis, the set of FBRs that resulted in the highest number of nutrients ≥70% of the RNI for the lowest number of individual FBRs per set are shown in Table 6. The complete sets of systematic analyses are shown in Supplementary Appendix Tables S2–7. In Kitui and Vihiga, the maximum number of nutrients for which a set of FBRs would ensure dietary adequacy (i.e. minimised nutrient content was ≥70% of the RNI) was nine nutrients

Table 3. Observed median (quartiles) nutrient density of the complementary feeding diet compared with the WHO-desired levels

	Calcium*	Iron*	Zinc*	Vitamin A[†]	Vitamin C*	Vitamin B6*	Folate[‡]	Thiamin*	Riboflavin*	Niacin*
6–8 m[§]										
Desired[¶]	105	4.5	1.6	31	1.5	0.12	11	0.08	0.08	1.5
Kitui[‖]	39 (20, 74)	0.6 (0.4, 0.6)	0.5 (0.4, 0.6)	31 (18, 50)	0.6 (0.3, 2.2)	0.07 (0.06, 0.09)	6 (5, 10)	0.05 (0.04, 0.06)	0.07 (0.03, 0.12)	0.6 (0.4, 0.9)
Vihiga**	30 (16, 59)	0.5 (0.4, 0.6)	0.6 (0.5, 0.6)	34 (19, 56)	2.5 (0.6, 5.3)	0.08 (0.07, 0.11)	9 (7, 13)	0.05 (0.04, 0.06)	0.06 (0.05, 0.11)	0.5 (0.4, 0.6)
9–11 m[††]										
Desired[¶]	74	3	1.1	30	1.7	0.08	9	0.06	0.06	1.0
Kitui[‖]	19 (5, 49)	0.6 (0.4, 0.7)	0.5 (0.4, 0.5)	38 (26, 63)	1.8 (0.5, 4.6)	0.08 (0.07, 0.10)	7 (6, 12)	0.05 (0.04, 0.06)	0.04 (0.02, 0.06)	0.6 (0.5, 0.8)
Vihiga**	27 (10, 41)	0.6 (0.5, 0.7)	0.6 (0.5, 0.7)	41 (18, 72)	3.3 (0.8, 5.7)	0.09 (0.07, 0.11)	10 (7, 14)	0.06 (0.05, 0.06)	0.06 (0.04, 0.09)	0.6 (0.5, 0.7)
12–23 m[‡‡]										
Desired[¶]	63	1.0	0.6	23	1.5	0.08	21	0.07	0.06	0.9
Kitui[‖]	13 (3, 32)	0.7 (0.5, 0.7)	0.6 (0.4, 0.7)	29 (18, 49)	1.0 (0.2, 4)	0.08 (0.07, 0.09)	6 (5, 11)	0.05 (0.04, 0.06)	0.03 (0.02, 0.05)	0.5 (0.5, 0.7)
Vihiga**	21 (14, 36)	0.6 (0.6, 0.7)	0.5 (0.4, 0.6)	46 (21, 110)	3.8 (1.0. 7.5)	0.09 (0.07, 0.1)	12 (8, 17)	0.05 (0.05, 0.06)	0.06 (0.04, 0.08)	0.6 (0.5, 0.6)

*mg/100 kcal. [†]µg RE/100 kcal. [‡]µg DFE/100 kcal. [§]Mean (SD) energy intakes for 6–8 m in Kitui were 361 (±255) and in Vihiga were 384 (±272). [¶]2002 WHO-desired nutrient densities (Dewey & Brown, 2003). [‖]For Kitui, 6–8 m ($n = 49$), 9–11 m ($n = 32$), for 12–23 m ($n = 98$). **For Vihiga, 6–8 m ($n = 45$), 9–11 m ($n = 33$), for 12–23 m ($n = 78$). [††]Mean (SD) energy intakes for 9–11 m in Kitui were 463 (±204) and in Vihiga were 492 (±283). [‡‡]Mean (SD) energy intakes for 12–23 m in Kitui were 619 (±304) and in Vihiga were 581 (±265).

Table 4. Modelled problem nutrients identified in the complementary diets of breastfed children in Kitui and Vihiga Districts, Kenya*

Problem nutrient	Kitui			Vihiga		
	6–8 months	9–11 months	12–23 months	6–8 months	9–11 months	12–23 months
	% of RNI†			% of RNI†		
Calcium	—	—	—	68	88	86
Iron	31	33	66	21	30	60
Zinc	41	41	51	35	45	61
Niacin	—	—	—	98	—	—
Vitamin B12	—	—	88	—	—	—

*Problem nutrients were defined as those nutrients that cannot reach 100% of the RNI in the nutritionally best possible diets within model constraints. Models for Kitui assumed average breast milk intakes derived from the published average intakes for developing countries (WHO 1998); models for Vihiga assumed average breast milk intakes derived by subtracting median energy intakes from the complementary diet as determined by the 24-HR survey from estimated median energy requirements (FAO/WHO/UNU, 2004). †The % of RNI (WHO 2006b) is shown for the nutrient content from the Module II nutritionally best diet, assuming low bio-availability for iron and zinc.

Table 5. Individual food-based recommendations initially screened in the Module III analysis by age group and county

Food-based recommendations	Kitui			Vihiga		
	Servings per week*			Servings per week*		
	6–8 months	9–11 months	12–23 months	6–8 months	9–11 months	12–23 months
Fortified cereal products	7	7	7	3	3 or 4	2 or 4
Millet flour	7	7	7	—	—	—
Starchy roots and plant foods	4 or 7	4 or 7	7	4 or 7	4 or 7	4 or 7
Legumes	7	7 or 14	7 or 14	7	7	7
Milk	21	14 or 21	21	14	14	14 or 21
MFE	3 or 5	4	4	4 or 7	7	7
Small fish (*omena*)	3	3	3	5	5	5
Red meat	—	—	—	—	2	2
Fruit	—	—	4	3 or 7	5	—
Vegetables	21	28	28	21	28 or 35	28 or 35
GLV	7	7	7	7	7	7 or 14
Vitamin A-rich vegetables	—	—	—	3	—	2

*Servings per week screened in Module III.

among children 6–8 and 9–11 months old and seven nutrients among those 12–23 months old. For the younger two age groups, dietary adequacy was achieved with a minimum set of either four or five recommendations, with iron and zinc remaining as the problem nutrients. For children 12–23 months old, it was achieved with a minimum set of four to six recommendations, with calcium (Kitui only), folate (Vihiga only), iron, zinc and niacin remaining at <70% of the RNI. The minimised values for niacin were ≥60% of its RNI, which is less of a concern than for other nutrients. Niacin was expressed as micrograms of niacin instead of niacin equivalents, so additional niacin would be contributed by tryptophan. Likewise, folate and calcium are not a concern because their minimised values were close to the 70% criterion used in this study, which indicates that a low percentage of the population would be at risk of inadequate intakes. However, the lowest diet costs for these sets of FBRs were 1.7–3.0 times higher than the modelled diets without recommendations (Table 6).

Table 6. Baseline and best sets of food-based recommendations with the lowest market price by county and age group

Baseline and Food-based recommendations*	Cost (KSh[†]/ week)	Nutrients < 70% RNI in Module III (minimised diets)
Kitui		
6–8 months		
No recommendations	4.6	Calcium, iron, zinc, vitamins A, B1, B2, B3, B9, B12, C
Milk (21) + GLV[‡] (7) + Millet (7) + Cereal, fortified cereal flour (7)	18.2	Iron (19%)[§], zinc (26%)
9–11 months		
No recommendations	4.9	Calcium, iron, zinc, vitamins A, B1, B2, B3, B9, B12, C
Milk (21) + GLV (7) + Millet (7) + Cereal, fortified cereal flour (7)	19.1	Iron (21%), zinc (30%)
12–23 months		
No recommendations	6.9	Calcium, iron, zinc, vitamins A, B1, B2, B3, B9, B12, C
Milk (21) + GLV (7) + Legumes (14) + Fish, small fish (3) + Millet (7) + Cereal, fortified cereal flour (7)	24.2	Calcium (65%), iron (55%), zinc (43%), vitamin B3 (61%)
Vihiga		
6–8 months		
No recommendations	4.1	Calcium, Iron, zinc, vitamins B1, B2, B3, B6, B9
Milk (14) + Legumes (7) + GLV (7) + Fish, small fish (5) + Cereal, fortified cereal flour (3)	14.4	Iron (13%), zinc (31%)
9–11 months		
No recommendations	5.9	Calcium, iron, zinc, vitamins B2, B3, B6, B9, C
Milk (14) + Legumes (7) + GLV (7) + Fish, small fish (5) + Cereal, fortified cereal flour (3)	16.1	Iron (14%), zinc (31%)
12–23 months		
No recommendations	9.3	Calcium, iron, zinc, vitamins A, B1, B2, B3, B9, B12, C
Milk (21) + Legumes (7) + GLV (14) + Cereal, fortified cereal flour (4)	26.9	Iron (38%), zinc (36%), vitamins B3 (51%), B9 (66%)
Milk (21) + Legumes (7) + GLV (14) + Fish, small fish (5) + Cereal, fortified cereal flour (4)	28.9	Iron (41%), zinc (43%), vitamins B3 (60%), B9 (67%)

*The number in the parenthesis shows the recommended number of servings per week. For example, Milk (21) is 21 servings of milk per week. [†]KSh—Kenyan Shillings; exchange rate was approximately 1Ksh = 0.012 US$ in August 2012. [‡]GLV—green leafy vegetables. [§]Nutrient (% RNI).

The final sets of FBRs selected are summarised in Table 7. Breastfeeding on demand is included, in all sets of FBRs, to reinforce the importance of breast milk and to emphasise that these recommendations are intended to complement, not replace, breast milk. Recommendations for children 6–8 and 9–11 months old were similar and, hence, were combined for simplicity. Recommendations for children 12–23 months old were similar to those for children 9–11 months old, with a few additions and modifications.

The sensitivity analyses showed that iron and zinc remained problem nutrients for children 6–8 and 9–11 months old in both counties, regardless of the RNIs used. However, for children 12–23 months old, zinc was no longer a problem nutrient when the IZiNCG instead of the WHO RNI was used. Thus, for the oldest age group, conclusions about problem nutrients were sensitive to the RNIs selected.

Discussion

This analysis identified the nutrient intake gaps among breastfed children in two distinct, rural Kenyan populations, and it demonstrated that the gaps for most

Table 7. Summary of food-based recommendations for children 6–11 and 12–23 months of age in Kitui and Vihiga Districts, Kenya

County	Target group	
	6–11 months	12–23 months
Kitui	• Breastfeed on demand • Heat-treated full fat cows' or goats' milk ≥3 times per day (e.g. adding milk to porridge)* • Fortified cereal at least once per day • GLV[†] once per day • Millet flour once per day • Either legumes or MFE[‡] once per day	• Breastfeed on demand • Heat-treated full fat cows' or goats' milk ≥3 times per day (e.g. adding milk to porridge) • Fortified cereal at least once per day • GLV once per day • Millet flour once per day • Legumes twice per day • MFE every day, especially small fish ≥3 times per week
Vihiga	• Breastfeed on demand • Heat-treated full fat cows' or goats' milk ≥2 times per day (e.g. adding milk to porridge) • Fortified cereal ≥3 times per week • GLV once per day • Bean flour once per day (as porridge ingredients) • Small fish ≥5 times per week	• Breastfeed on demand • Heat-treated full fat cows' or goats' milk ≥3 times per day (e.g. as a drink or adding to porridge) • Fortified cereal ≥4 times per week • GLV ≥2 times per day • Legumes or bean flour (as porridge ingredient) once per day • Small fish ≥5 times per week

*Animal milk should not be fed during episodes of diarrhoea without providing extra non-milk fluids, as its relatively high potential renal solute load can lead to hypernatremic dehydration (WHO, 2005). [†]GLV—green leafy vegetables. [‡]MFE-meat, fish, egg.

nutrients could be meaningfully reduced by altering the consumption frequency of available food items in the complementary diet. The analysis identified sets of four to six FBRs selected from the lowest cost options that could fill those gaps. The analysis also identified two to four nutrients for which intake requirements could not be met within the existing dietary pattern and for which additional interventions would be required. These results provide an evidence base for designing and testing interventions to improve the nutritional quality of the IYC diet in these vulnerable populations.

The nutritional quality of the complementary diets of these children compared with the WHO-desired levels was very poor when expressed as median nutrient densities. This is consistent with the high prevalence of low dietary diversity observed. Diversity of food groups among children 6–23 months old in developing country regions was previously shown to be positively related to the mean micronutrient density adequacy (Working Group on Infant and Young Child Feeding Indicators 2006).

This nutrient intake gap analysis is based on estimates of inadequate intakes in comparison to theoretical nutrient intake requirements, and therefore does not imply the presence of clinical or sub-clinical nutrient deficiency states. Nonetheless, these estimates are reflective of an elevated risk for deficiencies of multiple nutrients in these populations, for which there is some, albeit limited, evidence among children in Kenya. The 1999 National Micronutrient Survey indicated that the prevalence of biochemical deficiencies of vitamin A, iron and zinc in children were high, at 84%, 20% and 51%, respectively (Ministry of Health et al. 1999). Non-representative community-based studies have reported elevated prevalence rates of iron and vitamin A deficiencies among infants and young children in western Kenya (Grant et al. 2012; Suchdev et al. 2012), and of iron, zinc, vitamin A, riboflavin and vitamin B12 (but not folate) among school children in eastern Kenya (Siekmann et al. 2003). More studies directly linking inadequate nutrient intakes and bio-chemical and/or clinical evidence of nutrient deficiencies would be useful to strengthen the dietary intake-based evidence and recommendations derived from this type of analysis.

The Optifood LPA for diet optimisation indicated that sufficient diversity existed within the boundaries of the current dietary pattern in both locations to increase the intake adequacy for most of the 11 micronutrients considered. For those nutrients, improved dietary adequacy could potentially be achieved by increasing the diversity of individual IYC diets by feeding nutrient dense foods from a higher number of food groups on a daily basis than is currently being done, i.e. from at least five food groups vs. observed mean dietary diversity scores ranging from 2.1 to 3.7 food groups, depending on the age group and county. The FBRs are expressed as a recommended number of servings per week – this could be accomplished by increasing the frequency (i.e. number of days) that the food is served per week or, alternatively, by increasing the portion size served at one feeding such that more than one median-sized serving is offered. It may thus be possible to improve the dietary adequacy of these children through behaviour change communication (BCC).

Subsequent studies in these communities are required to test the acceptability of these initial FBRs and to assess any barriers to their adoption. While some of the recommendations represent only minor changes to current dietary patterns, a few represent more substantial changes, such as to feed children MFE and fortified cereal in Kitui, and legumes and small fish in Vihiga, all of which were consumed by <5% of children. These recommended foods were selected because of their availability in the communities and their potential to improve nutrient intake adequacy. If some recommendations are found to be unfeasible, alternative FBRs could be explored that would meet the same objectives.

Based on our analysis of the local market price of foods, incorporation of these sets of recommendations could result in a large, 1.7- to 3.0-fold increase in the cost of the diet if all foods were purchased. Considering the high prevalence of households living in poverty, this increase may not be feasible. In this case, interventions that are aimed at lowering the cost of these nutritious foods should be explored, including increased self-production and more efficient market value chains (Hotz et al. submitted).

The analysis identified some nutrients as being problem nutrients. It is very difficult to meet iron requirements and challenging to meet zinc requirements from the IYC diet as the amount of iron and zinc in breast milk is very low, and the majority of these nutrients must be obtained from foods (WHO 1998). The sensitivity analyses also showed that iron and zinc (in children 6–11 months old only) would remain problem nutrients even if their absorption was enhanced from low to moderate levels. The intakes of these nutrients are so low in relation to requirements in IYC diets that the analyses' conclusions are not highly sensitive to assumptions around bio-availability; suggesting intervention strategies to enhance the absorption of these nutrients might be insufficient to ensure population-level dietary iron and zinc adequacy. Calcium was a problem nutrient for all three age groups in Vihiga, but not in Kitui, and this can be attributed to the reported use of a commercial millet flour mix with added calcium in Kitui only, and differences in the serving sizes reported for fluid milk. The recommendation to feed heat treated full fat fluid cows' or goats' milk in porridges two or three times a day will improve dietary adequacy for calcium and zinc. Heat treatment of these animal milks is important for reducing risks of disease transmission and gastrointestinal blood loss in children that can occur following raw milk consumption (WHO, 2005). The recommended small serving sizes (<100 g/d) mixed into porridges addresses concerns that high renal solute loads of animal milks may lead to hypernatremic dehydration in water stressed infants, as long as care is taken to ensure adequate hydration during diarrhoeal illnesses (WHO, 2005).

To address the three main problem nutrients (calcium, iron and zinc), additional low-cost foods that are rich sources of these nutrients would need to be introduced into the local food supply and adopted by caregivers for IYC feeding. Such interventions may include low-cost fortified flour mixes (Bruyeron et al. 2010; Das et al. 2013); increased accessibility of animal-source foods, particularly meat (Neumann et al. 2003); and appropriately formulated micronutrient powders that have been shown to reduce iron and vitamin A deficiency when made available for sale to caregivers in western Kenya (Suchdev et al. 2012).

If new foods or fortified products can be successfully introduced into these communities to address low intakes of problem nutrients, these same items could potentially result in increased intakes of other nutrients. In this case, the FBRs could be remodelled, possibly resulting in a smaller number of FBRs required to improve nutrient intake adequacy.

Despite the obvious differences in the agro-ecology and seasons in which the surveys were conducted and diversity of foods in the two study sites, nutrient intake adequacies and the initial FBRs did not differ substantially. Although lower dietary diversity was observed in the semi-arid area near the end of the food shortage season compared with the more fertile region during the food plenty season, diversity was still quite restricted in both areas. The reasons for this were not studied directly, but it is suggestive of limited accessibility to a wide range of foods because of limited purchasing power, under-developed food value chains or cultural practices around IYC feeding.

This analysis relied on assumptions about breast milk intakes and its nutrient content; the accuracy of food nutrient composition values of complementary foods, especially millet; and the RNIs for children 6–23 months old, and it assumed that the total energy intakes of these children were adequate. Breast milk was an important food source for 8 to 10 of the 11 micronutrients modelled in the Module II nutritionally best diets, depending on the target group. Thus, a marked discrepancy between modelled and actual intakes of breast milk or between its modelled and actual nutrient composition could modify the conclusions. The reported high prevalence of stunting and low prevalence of wasting among young Kenyan children is consistent with the presence of nutrient deficiencies but not energy deficiencies (KNBS, ICF Macro 2010). Further, the model parameters, which defined the upper and lower food pattern constraint levels for the simulated 7-day diets, were derived from a single 24-h recall, which will allow more foods to be selected from the less regularly consumed food groups, such as MFE, than would habitually occur. This limitation might result in an under-estimation of the number of problem nutrients or an over-estimation of the number of nutrients for which dietary adequacy is not ensured.

In summary, this analysis showed that the nutritional quality of the complementary diet was restricted in these two distinct rural Kenyan populations, but that it could be improved through the careful selection of foods. For children 6–11 months of age, a set of four to five FBRs would ensure dietary adequacy for 9 of the 11 micronutrients modelled, while for children 12–23 months of age, five to six recommendations would ensure adequacy for seven micronutrients. Iron and zinc in both sites, plus calcium in Vihiga, were the main problem nutrients, and, for these nutrients, external solutions, such as fortification, would be required to ensure adequate intakes. The costs of ensuring dietary adequacy, however, were high relative to reported monthly incomes, suggesting that multiple approaches, including income-generation activities, lowering food market prices or increasing home-production, are likely required to support efforts to achieve nutritionally adequate complementary diets in these populations.

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Conflicts of interest

The authors report no conflict of interest associated with this work.

References

Black R.E., Victora C.G., Walker S.P., Bhutta Z.A., Christian P., de Onis M. *et al.* (2013) Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet* **382**, 427–451.

Bruyeron O., Denizeau M., Berger J. & Treche S. (2010) Marketing complementary foods and supplements in Burkina Faso, Madagascar, and Vietnam: lessons learned from the Nutridev program. *Food and Nutrition Bulletin* **31**, S154–S167.

CRA (2011) *Kenya County Fact Sheets*. Nairobi: CRA.

Daelmans B., Ferguson E., Lutter C.K., Singh N., Pachon H., Creed-Kanashiro H. *et al.* (2013) Designing appropriate complementary feeding recommendations: tools for programmatic action. *Maternal and Child Nutrition* **9** (Supplement 2), 116–138.

Das J.K., Salam R.A., Kumar R. & Bhutta Z.A. (2013) Micronutrient fortification of food and its impact on women and child health: a systematic review. *Systematic Reviews* **23**, 2–67.

De Lauzaon B., Volatier J.L. & Martin A. (2004) A Monte Carlo simulation to validate the EAR cut-point method for assessing the prevalence of nutrient inadequacy at the population level. *Public Health Nutrition* **7**, 893–900.

Dewey K.G. & Brown K.H. (2003) Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs. *Food and Nutrition Bulletin* **24**, 5–28.

FAO/WHO/UNU (2004) Human energy requirements. In: *Report of a Joint FAO/WHO/UNU Expert Consultation*, *FAO Food and Nutrition Technical Report Series #1*. FAO: Rome.

Ferguson E., Darmon N., Fahmida U., Fitriyanti S., Harper T. B. & Premachandra I.M. (2006) Design of optimal food-based complementary feeding recommendations and identification of key 'problem nutrients' using goal programming. *Journal of Nutrition* **136**, 2399–2404.

Gibson R.S. & Ferguson E. (2008) An interactive 24-hour recall for assessing the adequacy of iron and zinc intakes in developing countries. In: *HarvestPlus Technical Monograph 8*. IFPRI and International Center for Tropical Agriculture (CIAT): Washington, DC and Cali, Colombia.

Grant F.K.E., Martorell R., Flores-Ayala R., Cole C.R., Ruth L.J., Ramakrishnan U. *et al.* (2012) Comparison of indicators of iron deficiency in Kenyan children. *American Journal of Clinical Nutrition* **95**, 1231–1237.

Hotz C. & Brown K. (2004) Assessment of the risk of zinc deficiency in populations and options for its control. *Food and Nutrition Bulletin* **25** (Suppl 2), S91–S202.

Hotz C., Ferguson E., Kennedy G. & Woldt M. (2011) *Standard Operating Procedures for the Compilation of the Optifood Food Composition Table*Version 9. Academy for Educational Development/Food and Nutrition Technical Assistance Project: Washington, DC.

Hotz C., Pelto G., Armar-Klemesu M., Ferguson E., Chege P. & Musinguzi E. (submitted) Constraints and opportunities for implementing nutrition-specific and nutrition-sensitive intervention approaches to improve nutrient intake adequacy among infants and young children in two regions of rural Kenya. *Maternal and Child Nutrition*.

Institute of Medicine (1991) *Nutrition During Lactation*. National Academy Press: Washington, DC.

Kenya National Bureau of Statistics (KNBS) & ICF Macro (2010) *Kenya Demographic and Health Survey 2008–09*. Calverton, Maryland: KNBS and ICF Macro.

Ministry of Health [Kenya], KEMRI, University of Nairobi, SOMA-NET & UNICEF (1999) *Anaemia and the Status of Iron, Vitamin-A and Zinc in Kenya*. National Micronutrient Survey Report: Nairobi.

Neumann C.G., Bwibo N.O., Murphy S.P., Sigman M., Whaley S., Allen L.H. *et al.* (2003) Animal source foods improve dietary quality, micronutrient status, growth and cognitive function in Kenyan school children: background, study design and baseline findings. *Journal of Nutrition* **133**, 3941S–3949S.

Siekmann J.H., Allen L.H., Bwibo N.O., Demment M.W., Murphy S.P. & Neumann C.G. (2003) Kenyan school children have multiple micronutrient deficiencies, but increased plasma vitamin B-12 is the only detectable micronutrient response to meat or milk supplementation. *Journal of Nutrition* **133**, 3972S–3980S.

Suchdev P.S., Ruth L.J., Woodruff B.A., Mbakaya C., Mandava U., Flores-Ayala R. *et al.* (2012) Selling sprinkles micronutrient powder reduces anemia, iron deficiency, and vitamin A deficiency in young children in Western Kenya: a cluster-randomized controlled trial. *American Journal of Clinical Nutrition* **95**, 1223–30.

WHO (1998) *Complementary Feeding of Young Children in Developing Countries: A Review of Current Scientific Knowledge*. WHO: Geneva.

WHO (2005) *Guiding Principles for Feeding Non-Breastfed Children 6–24 Months of Age*. WHO: Geneva.

WHO (2006a) *WHO Child Growth Standards*: *Length/Height-for-Age, Weight-for-Age, Weight-for-Length, Weight-for-Height and Body Mass Index-for-Age: Methods and Development*. WHO: Geneva.

WHO (2006b) *Vitamin and Mineral Requirements in Human Nutrition*, 2nd edn. Geneva: WHO.

WHO, UNICEF, USAID, Academy for Educational Development & University of California – Davis & IFPRI (2008) *Indicators for Assessing Infant and Young Child Feeding Practices: Conclusions of a Consensus Meeting Held 6–8 November 2007 in Washington, DC*. WHO: Geneva.

WHO/UNICEF (2003) *Global Strategy for Infant and Young Child Feeding*. WHO: Geneva.

Working Group on Infant and Young Child Feeding Indicators (2006) *Developing and Validating Simple Indicators of Dietary Quality and Energy Intake of Infants and Young Children in Developing Countries: Summary of Findings from Analysis of 10 Data Sets*. FHI 360/Food and Nutrition Technical Assistance Project (FANTA): Washington, DC.

Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Description of the models within Optifood Modules I–III.

Table S2. Tests of alternative sets of food-based recommendations for children 6–8 months old in Kitui; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).

Table S3. Tests of alternative sets of food-based recommendations for children 9–11 months old in Kitui; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).

Table S4. Tests of alternative sets of food-based recommendations for children 12–23 months old in Kitui; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).

Table S5. Tests of alternative sets of food-based recommendations for children 6–8 months old in Vihiga; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).

Table S6. Tests of alternative sets of food-based recommendations for children 9–11 months old in Vihiga; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).

Table S7. Tests of alternative sets of food-based recommendations for children 12–23 months old in Vihiga; the nutrient content of the minimised diet, for each nutrient, expressed as a percentage of its WHO/FAO Recommended Nutrient Intake (RNI).