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ORIGINAL ARTICLE

Combining food-based dietary recommendations using Optifood with zinc-fortified water potentially improves nutrient adequacy among 4- to 6-year-old children in Kisumu West district, Kenya

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Abstract

Children in developing countries often face multiple micronutrient deficiencies. Introduction of zinc-fortified water can increase zinc intake, but additional recommendations are required to address overall diet nutrient adequacy. We developed and tested food-based recommendations (FBRs) that included zinc-fortified water for children aged between 4 and 6 years from rural Kenya to achieve the best possible nutrient adequacy. Dietary intakes of 60 children aged 4–6 years, from Kisumu West district, Kenya, were assessed using a quantitative multipass 24-hr recall. Linear programming model parameters were derived, including a list of foods consumed, median serving sizes, and distribution of frequency of consumption. By using the Optifood linear programming tool, we developed FBRs for diets including zinc-fortified water. FBRs with nutrient levels achieving ≥70% recommended nutrient intake (RNI) of the World Health Organization/Food and Agriculture Organization of the United Nations RNI for most of the 12 considered nutrients were selected as the final recommendations for the children. With no FBRs and no zinc-fortified water, percent RNI coverage range was between 40% and 76% for zinc, improving to 66–101% after introduction of zinc-fortified water. The final set of FBRs achieved nutrient adequacy for all nutrients except for vitamin A (25% RNI) and folate (68% RNI). Introduction of zinc-fortified water combined with FBRs will likely improve the nutrient adequacy of diets consumed by children in Kenya but needs to be complemented with alternative interventions to ensure dietary adequacy.

KEYWORDS

Optifood, children, diets, water, zinc

1 | INTRODUCTION

Zinc (Zn) deficiency is common in children in developing countries leading to poor growth and decreased immune competence (Hambidge, 2000). Twenty-six percent of children under 5 years old in Kenya are estimated to be at risk of zinc deficiency (Kenya National Bureau of Statistics [KNBS], 2015). An important cause of zinc deficiency is inadequate dietary zinc intake or low zinc bioavailability in plant-based foods, due to the presence of absorption inhibitors such as phytic acid (Lonnerdal, 2000).

Food fortification with zinc is currently recommended as a strategy to address zinc deficiency (Brown, Hambidge, Ranum, & Zinc Fortification Working Group, 2010). As cereal foods contain phytic acid, the zinc absorption inhibition may persist in fortified cereals affecting bioavailability of native and fortificant zinc (Brown et al., 2010). Fortification of drinking water promises to overcome this as the zinc from an aqueous solution has been reported to be highly bioavailable in particular, if consumed away from meals (Sandstrom, Davidsson, Cederblad, & Lonnerdal, 1985). An additional benefit of consuming microbiological clean drinking water might be a reduction of diarrhoea, both a cause and consequence of zinc deficiency (Wapnir, 2000). In a recent isotopic study, zinc from fortified water was found to be nine times more bioavailable than zinc from fortified cereal, and in an efficacy trial in rural Beninese children, it sustained significantly higher plasma zinc levels (Galetti et al., 2015).

Resource-poor populations often face multiple micronutrient deficiencies concurrently due to inadequate intakes, low bioavailability, and frequent infections (Muthayya et al., 2013; Siekmann et al., 2003; Torheim, Ferguson, Penrose, & Arimond, 2010). Zinc is one of the critical nutrients in addition to iron, iodine (Joy et al., 2014; Muthayya et al., 2013), and vitamins A and B (Muthayya et al., 2013; Ramakrishnan, 2002). In low- and middle-income countries, it is estimated that more than 25% of the population is at risk of inadequate zinc intake (Wessels, Singh, & Brown, 2012). Kenya is estimated to have a high prevalence of hidden hunger and is ranked second out of 149 countries using the hidden hunger index developed in 2013 by Muthayya et al. (2013). Food-based recommendations (FBRs) for young children and adults in multi-micronutrient deficiency settings developed through mathematical programming (Briend, Darmon, Ferguson, & Erhardt, 2003; Ferguson et al., 2006; Maillot et al., 2009) can assist in defining a strategy to achieve nutrient adequacy in a well-defined, local setting. However, in most situations, adequacy cannot be reached by any combination of local foods, and alternative strategies such as fortification or supplementation may be needed (Allen, de Benoist, Dary, & Hurrell, 2006). Especially for zinc, it has been repeatedly demonstrated that nutrient adequacy cannot be reached through local food-based dietary recommendations in different settings (Fahmida et al., 2015; Ferguson et al., 2006; Levesque, Delisle, & Agueh, 2015; Santika, Fahmida, & Ferguson, 2009). Combining a recommendation to consume zinc-fortified drinking water with FBRs could provide such an alternative to improve zinc intake specifically, but also overall nutrient adequacy.

Optifood uses linear modelling to develop FBRs on the basis of local dietary patterns to achieve nutrient adequacy (Briend et al., 2003). This mathematical modelling approach provides an objective method to predict, for example, whether fortification, supplementation, or special complementary food products are needed to ensure dietary adequacy of young children (6–23 months) from high-risk populations, and the extent to which they might contribute to its achievement (FANTA, 2013; Skau et al., 2014). No studies to date have combined FBRs with introduction of zinc-fortified water. On the basis of dietary data collected in rural Western Kenya, we developed and tested FBRs that include zinc-fortified water for children aged between 4 and 6 years to achieve the best possible nutrient adequacy.

2 | SUBJECTS AND METHODS

2.1 | Study area and design

The study was conducted in Kisumu West district, western Kenya. This district has a population of about 123,447 people drawn from 29,043 households, being mainly rural and lacking access to many basic health care services. The main economic activities are small-scale farming and fishing restricted to parts bordering Lake Victoria. This research site was chosen due to high prevalence of zinc deficiency (KNBS and ICF Macro, 2010), diarrheal disease (Adazu, 2005; Tornheim, 2010), and high surface water usage (Bennett et al., 2015; KNBS and ICF Macro, 2010).

Key messages

- Optifood is a useful tool to show objectively the contribution that zinc-fortified water can make when introduced in food-based recommendations to meeting the nutrient needs of rural Kenyan children.
- Introduction of zinc-fortified water should be accompanied by FBRs to improve nutrient adequacy of the whole diet in order to address multiple micronutrient deficiencies.
- As the recommendations are based on local dietary patterns, they may be considered as realistic and achievable by some, but may ask for substantial changes for others. Consultation with local stakeholders is essential to identify barriers and supporting factors that could encourage their adoption.

The research protocol was approved by the Ethical Review Committee of Kenyatta National Hospital/University of Nairobi (KNH-ERC/A/335) and ETH Zurich Ethical review committee (EK 2013-N-31). It was presented to local leaders who gave their approval for it to be conducted. Written informed consent was obtained from the household head and caregiver on behalf of their child before the research commenced.

2.1.1 | Subjects

A dietary assessment was carried out among a sample of 112 randomly selected preschool children in August 2014 to quantify the daily dietary and water intake during the preharvest season. The sample size was estimated to be adequate to determine a mean daily zinc intake deviating less than 0.3 mg from the true intake with 80% power and 95% confidence, assuming an expected mean intake of 2.8 mg/day with an anticipated *SD* of 1.5 mg/day (Gegios et al., 2010; Gibson & Fergurson, 1999) and a 10% nonresponse rate. Children between 4 and 6 years (n = 62) constituted the largest age group in the dietary study subsample and therefore were considered the target group for the Optifood analysis.

2.2 | Survey data collection

2.2.1 | Dietary assessment

Dietary intake of the children was assessed using a quantitative multipass 24-hr recall method (Blanton, Moshfegh, Baer, & Kretsch, 2006; Conway, Ingwersen, Vinyard, & Moshfegh, 2003; Gibson & Fergurson, 1999), with all recalls evenly distributed throughout the week. A second recall was carried out for each child on a nonconsecutive day to permit adjustment for day-to-day variation. The interviews were carried out by well-trained interviewers speaking fluent *Luo*. Children were randomly allocated to day of the week, interviewers were randomly allocated to households, and repeated household visits by the same interviewer were avoided. Caregivers were first asked to list all the foods and drinks the child had consumed at home and away in the previous 24 hr from waking up the day before the interview till waking up the day of interview. Then they were requested to mention all the ingredients and cooking methods for each food/dish. Duplicate amounts of all foods, beverages, and ingredients were weighed to the nearest 1 g using a digital balance scale (Kern EMB, Germany, max 5,200 g). If duplicate amounts were not available in the household during the interview, amounts were estimated using household units, in volume, or size (small, medium, or large) or as monetary equivalents. Caregivers were systematically probed for any food, beverage, or snack consumed outside the home or omitted during the interview. Standard recipes were generated to estimate the grams of ingredients consumed from mixed dishes purchased or eaten outside the home by averaging three recipes of different caregivers or vendors in the local area. For foods consumed at school, recipes were collected from the school cook. In all cases, proportion given to child was calculated as the total volume given to the child minus any leftovers divided by the total volume of food cooked by the caregiver/vendor/school. This proportion was multiplied by the total amount of ingredients used in preparing the dish to determine amount consumed by the child.

2.2.2 | Drinking water intake assessment

Consumption of both unfiltered and filtered (both unfortified and fortified) drinking water was assessed for each child during the 25 weeks of the intervention. All study children were provided with cups of standard volume 300 ml graduated at 75, 150, and 125 ml. A personal diary was filled out by each caregiver every day to record the participating child's water intake by placing a tally mark under the image corresponding to the day of week, type of water consumed (filtered or unfiltered), and administered volume whenever the index child consumed water. For each child, the median daily drinking water amount over the intervention period was determined.

2.2.3 | Drinking water zinc content

Water was sampled from 35 households weekly in February 2014, as follows: Samples were collected from the filters during a household visit into 10-ml polypropylene bottles prefilled with 0.5 ml of 2 M HNO_3 for zinc stabilization and transported to Kisumu in cooler boxes for zinc analysis by a rapid zinc assessment method (Aquaquant, Merck 1.14412.0001, Darmstadt, Germany).

2.2.4 | Weight and height

Anthropometry was measured in February 2014. Weight and height were measured in duplicate according to World Health Organization (WHO, 2008) guidelines to the nearest 0.1 kg and 0.1 cm, respectively, using an electronic scale (Ashton Meyers, England, United Kingdom), and a UNICEF wooden three-piece measuring board with a sliding head piece. The weighing scale was calibrated daily.

2.2.5 | Blood sampling

Blood sampling was conducted in February 2014. Blood samples were collected between 8:00 a.m. and 13:00 p.m. from fasting and nonfasting subjects for plasma zinc (PZn) analysis according to IZINCG (2012) protocol. Blood was drawn from subject's vein into lithium heparin trace element free Monovette Sarsted system tubes. To obtain plasma, blood was centrifuged at 3,000 revolutions per minute for 10 min in the field within 40 min of collection. Plasma samples were aliquoted into acid-washed Eppendorf containers (500 μl) in duplicate for zinc analysis and in triplicate into regular tubes (150 μl) for analysis of C-reactive protein, alpha 1 acid glycoprotein (AGP), plasma ferritin (FER), soluble transferrin receptor (sTfR), and retinol binding protein (RBP). The aliquots were kept in a cooler box before transportation on the same day to Maseno University for storage at −20 °C. All samples were then sent to ETH Zurich, Switzerland, on dry ice for analysis of PZn concentration and to Germany for analysis of the proteins using a sandwich enzyme-linked immunosorbent assay technique (Erhardt, Estes, Pfeiffer, Biesalski, & Craft, 2004). Haemoglobin was analysed in the field on the spot on a separate venous blood sample using a HemoCue photometer (HemoCue HB 201, Ängelholm, Sweden).

2.3 | Data analysis

2.3.1 | Nutrition status

z scores, for height for age (HAZ) and body mass index for age (BAZ), were calculated for each child using WHO ANTHRO PLUS (WHOv1.0.4; www.who.int/childgrowth/software/en/). Children were classified as stunted or thin if their HAZ and BAZ were less than −2 *SD*, respectively (WHO, 2008). We measured nutritional and inflammation status of the population by measuring the following biomarkers PZn (flame atomic absorption spectrometry; AA240FS, Varian Inc., Australia) and the following proteins: FER, sTfR, RBP, C-reactive protein, and AGP by a procedure that combines analytes using a sandwich enzyme-linked immunosorbent assay technique (Erhardt et al., 2004). We calculated prevalence of low PZn by using sex and age-specific lower cut-offs by IZINCG (Brown et al., 2004): PZn < 65 μg/dl for blood samples collected during the morning and PZn < 57 μg/dl for the afternoon samples irrespective of fasting status. Subclinical inflammation was defined as C-reactive protein > 5 mg/l and/or AGP > 1 g/L. Applied cut-off for haemoglobin was <110 g/L in children below 59 months and 115 g/L for children ≥ 60 months (McLean, Cogswell, Egli, Wojdyla, & de Benoist, 2009). The thresholds for defining iron deficiency were FER < 12 μg/L or sTfR > 8.3 mg/L. Vitamin A deficiency was defined by RBP < 0.75 μmol/L. PZn, FER, and RBP were corrected for inflammation using the Thurnham method (Thurnham, Mburu, Mwaniki, & Wagt, 2005).

2.3.2 | Habitual nutrient intakes

Compl-eat© (version 1.0, Wageningen University, The Netherlands) was used to calculate energy and nutrient intakes from the 24-hr recalls. The following nutrients were considered: protein, fat, carbohydrates, calcium, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12}, vitamin A, iron, and zinc. Energy and nutrient intake calculations were based on a food composition table (FCT) developed specifically for this study using the Kenya national FCT as primary source (Sehmi, 1993) complemented with data from FCTs from South Africa (Wolmarans, Danster, Dalton, Rossouw, & Schönfeldt, 2001), Mali (Barikmo, Ouattara, & Oshaug, 2004), East Africa (West, Pepping, & Temalilwa, 1988), International Minilist (Calloway, Murphy, Bunch, & Woerner, 1994), and the United States Department of Agriculture database (USDA, 2007). USDA retention factors (USDA & ARS, 2007) were applied to raw ingredients and foods to account for nutrient losses during food preparation. β-Carotene and retinol were converted into retinol activity equivalent using the International Vitamin A Consultative Group recommended conversion factors (IOM & FNB, 2001; IVACG, 2002). Energy and nutrient intake analysis was done using IBM SPSS (v21). Outliers were identified per nutrient according to the outlier labelling rule (Hoaglin, Iglewicz, & Tukey, 1986) and excluded from habitual intake analysis of that nutrient. Normality of distributions was tested visually using QQ plots. Nonnormal nutrient intake data were log transformed, resulting in normal distributions. All nutrient intakes were adjusted for day-to-day variation according to the method developed by the National Research Council (1986; Nusser, Carriquiry, & Fuller, 1992). The percentage of children below the EAR (Estimated Average Requirement) and the percent RNI coverage for each nutrient were determined.

2.3.3 | Preparation of model parameters

The 24-hr recall data were used to generate model parameters using Excel 2010 (Microsoft Corporation) and Access 2010 (Microsoft Corporation). These parameters were as follows: a list of noncondiment foods consumed by ≥5% of the target children, and per food the median serving size for those children that had consumed it, the minimum and maximum numbers of servings per week for the single foods, and (sub)food groups they belonged to. These were based on the 10th and 90th percentile distributions of serving counts. For fortified water, the minimum and maximum numbers of servings per week were set at 7, assuming this water would be provided every day to the child. The median daily drinking water consumed used in the modelling process was 477 ml/day based on the drinking water intake assessment, and the zinc concentration for zinc-fortified water was 1.15 mg/L.

An energy constraint was used to ensure all modelled diets provided the average energy requirement for the target group, estimated using reference mean body weight and the Food and Agriculture Organization of the United Nations (FAO)/WHO/UNU algorithm for estimating energy requirements (FAO, 2004). The FAO/WHO (FAO, 2010; FAO/WHO/UNU, 2007; WHO & FAO, 2004) RNI was used for the following nutrients: protein, fat, calcium, vitamin C, thiamin, riboflavin, niacin, vitamin B_6, folate, vitamin B_{12}, and vitamin A with 12.6 mg/day as RNI for iron (assuming 5% bioavailability) and 9.6 mg/day for zinc (assuming 15% bioavailability). Only for zinc-fortified water was the bioavailability of 65.9% used, on the basis of isotope studies conducted when fortified water was consumed between meals (Galetti et al., 2015).

2.3.4 | Optifood analysis

Analysis was carried out using Optifood (v4.0.9), a linear modelling approach to design population-specific FBRs (Daelmans et al., 2013; Ferguson et al., 2006; Ferguson, Darmon, Briend, & Premachandra, 2004; Maillot, Vieux, Amiot, & Darmon, 2010). Two scenarios were modelled: (a) diet with no zinc-fortified water-model parameters were entered without zinc-fortified water, and (b) diet with zinc-fortified water-model parameters are entered including zinc-fortified water.

Optifood Modules 1 and 2 were run for both scenarios. Module 1 was used to check feasibility of diets. This analysis step checks if (a) the model parameters can run correctly, (b) realistic diets can be generated for the target population, and (c) the possible range in the energy contents of diets is wide enough for modelling. Module 2 analysis was run to generate two best (optimized) diets. One average food pattern diet was optimized close to the average food pattern, and one best food pattern diet was optimized within the upper and lower food pattern limits but deviating more from the average food pattern. Module 2 best food pattern was used to identify nutrient-dense foods and their (sub)food group if their contribution to nutrient intake was ≥5% for any of the nutrients considered.

In Module 3, 26 diets were modelled comprising 13 minimized diets and 13 maximized diets. By selecting the low-nutrient-dense foods per food group, we modelled a minimized diet for each nutrient (worst case scenario). A maximized diet was modelled for each nutrient by selecting the high-nutrient-dense foods (best case scenario). Module 3 was run in three phases. In Phase I, the module was run without recommendations to identify problem nutrients. Problem nutrients were defined as unable to reach 100% RNI in best case scenario. Phases II and III were run to achieve ≥70% RNI for those nutrients that are unable to reach 70% RNI in worst case scenario in Phase I and increase percent RNI for problem nutrients as much as possible. As the percent RNI coverage in the no-fortified drinking water diet was the same as that for the fortified drinking water diet (except for zinc), Phase II was run only for the latter. In Phase II, food subgroups belonging to the nutrient-dense foods identified in Module 2 were added separately and in combination (Phase III) in the model. The FBRs with nutrient levels achieving ≥70% RNI in the worst case scenario for most nutrients were selected as the final FBRs for the children.

3 | RESULTS

3.1 | Study characteristics

Dietary data from 60 out of 62 children were used in the analysis as one child dropped out of the study and the second child turned 7 just at the time of the start of the study. The children had an average age of 62 months (Table 1). The percentage prevalence of stunting and thinness was 16% and 3%, respectively. Zinc deficiency was high in this population with 52% of the children having low plasma zinc (<65 μg/dl). Twenty-seven percent of the children suffered from vitamin A deficiency. The prevalence of anaemia, iron deficiency, and iron-deficiency anaemia was 52%, 63%, and 38%, respectively. Inflammation affected 53% of the children. Thirty-five out of the 60 children had more than one micronutrient deficiency.

3.2 | Food and nutrient intake

Data analysis included 120 dietary recalls (first and second recalls). Overall, 69 noncondiment food items were reported in the dietary

TABLE 1 Nutritional status of the children aged 4–6 years old Kisumu, Western Kenya, Kenya[a]

Characteristics	n = 60
Background	
Age, months	62 ± 8
Sex, girls, % (n)	63 (35)
Anthropometrics per age group[b]	
Height for age, z score	−1.0 ± 1.3
Children being stunted, % (n)	16.7 (10)
Body-mass-index for age, z score	−0.2 ± 0.9
Children being thin for their age % (n)	3.3 (2)
Micronutrient markers[c]	
Plasma zinc concentration, μmol/L	62 ± 10
Zinc deficiency,[d] % (n)	52 (31)
Haemoglobin concentration, g/L	108 ± 1.2
Anaemia,[e] % (n)	52 (32)
Iron deficiency,[f] % (n)	63 (37)
Iron-deficiency anaemia,[g] % (n)	38 (23)
Retinol binding protein concentration, μmol/L	0.9 ± 0.3
Vitamin A deficiency,[h] % (n)	27 (16)
Inflammation,[i] % (n)	53 (32)
Children with more than 1 nutrient deficiency, % (n)	35 (58)

Notes. n = 59 for zinc, iron, vitamin A deficiency, and inflammation biomarkers.

[a]Values are mean ± standard deviation unless stated otherwise.

[b]Children with z scores < −2 *SD* were considered as stunted and thin, respectively, according to WHO growth standards for children (<60 months) and WHO 2007 reference population (>61 months; WHO, 2008).

[c]Nutritional status biomarkers corrected for inflammation by Thurnham method (Thurnham, et al., 2005).

[d]Zinc deficiency: plasma zinc concentration < 65 μg/dl.

[e]Anaemia is defined as haemoglobin < 110 g/L for children below the age of 59 months and haemoglobin < 115 g/L for children 5–11 years.

[f]Iron deficiency: plasma ferritin concentration < 12 μg/L and/or soluble transferrin receptor > 8.3 mg/L.

[g]Defined as anaemia and plasma ferritin concentration < 12 μg/L and/or soluble transferrin receptor > 8.3 mg/L.

[h]Vitamin A deficiency: plasma retinol binding protein concentration < 0.75 μmol/L.

[i]Defined by plasma concentrations of C-reactive protein > 5 mg/L or alpha 1 acid glycoprotein >1 g/L.

recalls over the 2 days. From this list, 45 foods were consumed by more than 5% of the children and were included in the modelling (Table 2). Excluded condiments were baking soda and soup powder. Three foods (Brookside milk, okoko fish, and lemon) were excluded for having a maximum frequency consumption per week of below 1. Foods consumed by over 90% of the children were spring onion (96%), maize white flour (96%), brown sugar (96%), and tomato (90%). On average, children consumed these foods every day. Median serving sizes varied from 3.7 g/day for onion to 237 g/day for sour cow milk. Most foods (42 out of 45 foods) had serving sizes of more than 10 g/day. All children had iron and thiamin intake above the EAR. Respectively 36% and 2% of the children had energy and protein intake below their daily requirements (FAO, 2004). However, protein was mainly from plant-based resources such as legumes and maize, suggesting low biological value protein. More than 50% of children had intake below EAR for calcium, riboflavin, vitamin B_{12}, vitamin C, folate, and vitamin A. Respectively 19% and 49% of children had a low intake for vitamin B_6 and niacin (Table 3). Eighty-five percent of the children had a zinc intake below the EAR. The median percent RNI coverage without zinc-fortified water was 61%.

3.3 | Food pattern and nutrients of optimized diets

In Module 1, 20 realistic diets were generated for each possible diet (diet with and without zinc-fortified water). The Module 2 best food pattern covered the RNI for most nutrients except vitamin A and zinc for both diets, although percent RNI coverage for zinc was higher in the diet including zinc fortified (95.7%) compared to that of without fortified drinking water (70.8%). On the basis of this pattern, the foods (and their respective subfood groups) that contributed ≥5% to the intake of at least five or more nutrients were selected to be included in the modelling exercise in Module 3 (Table 4).

With no recommendation and no zinc-fortified water, percent RNI coverage range was between 40% (worst case scenario) and 76% (best case scenario) for zinc. This improved to 66% (worst case scenario) and 101% (best case scenario), suggesting that zinc nutritional adequacy can be reached by including zinc-fortified water in the recommendations (Table 5, Module III Phase I no recommendation).

Subsequently, recommendations for the subfood groups belonging to the selected nutrient-dense foods identified in Module 2 (Table 4) were added individually (Table 5) and in combination (Table 6) to the diet with zinc-fortified water, and for each combination, a new set of FBR was developed and tested. The final set of FBRs selected covered 87% of zinc RNI and contained whole grain products (two servings per day), fluid or powdered milk (one serving per day), nuts and seeds (four servings per week), vegetables (two servings per day) of which are rich in vitamin A (one serving per day) and vitamin C (one serving per day), starchy plants (one serving per day), and small whole fish with bones (one serving per day). Nutrient adequacy did not reach 70% for vitamin A (25% RNI) and folate (68% RNI) in the worst case scenario. The increased nutrient adequacy as percent RNI coverage in the final FBR compared to the children's actual median intakes is shown in Figure 1. The percent RNI coverage improved to over 100% for most nutrients (calcium, vitamin C, riboflavin, niacin, and vitamin B_{12}). Only for iron (98%) and zinc (87%) did intake remain below 100% RNI but above 70% RNI in the worst case scenario.

4 | DISCUSSION

The objective of this study was to develop FBRs that included zinc-fortified water to improve nutrient adequacy for children between 4 and 6 years in rural Kisumu, Kenya. We found that inclusion of zinc-fortified water with careful combination of local foods in realistic servings can substantially improve the nutritional quality of the diet. Addition of zinc-fortified water could improve the actual RNI coverage of 61% to a theoretical coverage of 87% even when low-nutrient-dense foods are consumed. Addition of fortified drinking water to FBRs can therefore substantially contribute to an adequate zinc

TABLE 2 Foods consumed by children (4–6 years), median serving sizes, and minimum and maximum servings per week in Kisumu, Western Kenya[a]

Food group and subfood group[b]	Food	Consumed by % of children[c]	Serving size[c] (g/day)	Min servings[d] per week	Median servings per week	Max servings[e] per week
Added fats						
Butter, ghee, margarine unfortified	Cooking fat	35	10.2	0	0	7
Vegetable oil unfortified	Cooking oil	86	20.3	0	7	7
Added sugars						
Sugar (unfortified)	Sugar, brown	96	39.1	1	6	6
	Sugar, white	15	26.9	1	1	1
Bakery and breakfast cereals						
Refined grain bread, unenriched/ unfortified	Bread, white	13	74.9	0	0	4
Beverages						
Other beverages	Drinking water[f]	100	477.0	7	7	7
Dairy products						
Fluid or powdered milk unfortified	Milk, cow, whole	80	100.0	0	6	6
	Milk, cow, sour	8	237.0	0	1	1
Fruits						
Vitamin C-rich fruit	Avocado	8	92.7	0	0	1
	Banana, yellow	8	152.0	0	0	1
	Mango, ripe	25	63.5	0	0	3
	Orange	5	45.5	0	0	1
	Papaya	5	36.7	0	0	1
Grains and grain products						
Enriched/fortified grains and products, whole or refined	Flour, wheat, Tropicana	56	16.3	0	4	7
Refined grains and products, unenriched/unfortified	Flour wheat white, in bread	56	14.3	0	4	7
Whole grains and products, unenriched/ unfortified	Flour, maize, white[g]	96	114.8	2	5	7
	Flour, maize, yellow[g]	32	127.3	1	2	2
	Flour, millet, red[g]	48	52.8	1	2	4
	Flour, sorghum[g]	18	38.2	0	1	1
	Maize grains white	45	93.0	1	2	3
	Maize grains yellow	8	93.1	0	0	1
	Maize, roasted	43	85.6	1	2	3
Legumes, nuts, and seeds						
Cooked beans, lentils, peas	Beans, piriton	6	42.3	0	0	1
	Beans, red	8	29.2	0	0	1
	Beans, cocoa rose	16	35.0	0	0	2
	Cowpeas seeds	12	50.0	0	0	2
	Greengrams	13	78.2	0	0	2
Nuts, seeds, and unsweetened products	Groundnuts raw	10	67.6	0	0	2
	Groundnuts prepared	8	44.0	0	0	2

Notes.

[a]All foods consumed by at least 5% of the children (n = 60).

[b]Food groups and food subgroups as defined by Optifood programme.

[c]Values are median serving sizes of the raw edible portions when consumed on the basis of 24-hr recalls.

[d]Minimum frequencies were calculated on the basis of the 10th percentile of distribution of the serving counts with consideration of proportion consuming each food within each food subgroup.

[e]Maximum frequencies were calculated on the basis of the 90th percentile of distribution of the serving counts with consideration of proportion consuming each food within each food subgroup.

[f]As assessed during the course of the study using personal diaries.

[g]Unrefined cereal flour.

intake. But still, FBRs are required to increase nutrient adequacy of the remaining nutrients. Calcium, vitamin C, riboflavin, niacin, vitamin B_{12}, thiamine, B_6, iron, and zinc achieved >70% RNI in the final FBRs. However, adequate intake of vitamin A and folate could not be ensured even when high-nutrient-dense foods were included.

The diet of the children was characterized by low variation in food intake. Only 45 foods were consumed by ≥5% of the population. Cereals and legumes were consumed in larger quantities and higher frequency than were nutrient-dense foods such as animal source foods (ASFs). Other studies also confirm that in Kenyan children,

TABLE 3 Nutrient intake of the children aged 4–6 years and percent below EAR without zinc-fortified water[a]

Nutrient	Intake[b]	% below EAR[c]	% of RNI[b,d]
Energy (kcal/day)	1,464 [1,328, 1,653]	36[e]	
Protein (g)	36 [30, 41]	2[f]	192 [158, 216]
Calcium (mg/day)	456 [352, 600]	60	76 [59, 100]
Iron (mg/day)	10 [9, 12]	0	82 [73, 99]
Thiamin (mg/day)	0.7 [0.6, 0.8]	0	134 [114, 154]
Riboflavin (mg/day)	0.4 [0.4, 0.6]	52	82 [67, 103]
Vitamin B_6 (mg/day)	0.8[0.6, 1.2]	19	150 [96, 211]
Vitamin B_{12} (μg/day)	0.8 [0.4, 1.2]	58	73 [41, 104]
Vitamin C (mg/day)	23 [13, 28]	55	77 [50, 99]
Folate (μg DFE/day)	99 [94, 106]	100	50 [47, 54]
Niacin (mg/day)	6 [4, 8]	49	75 [58, 99]
Vitamin A (μg RAE/day)	86 [54, 116]	55	18 [12, 24]
Zinc (mg/day)	5.8 [4, 6.6]	85	61 [46, 73]

Notes. DFE = dietary folate equivalents; RAE = retinol activity equivalent.

[a]Excluson of outlier nutrient intakes using outlier labelling rule (Hoaglin, et al., 1986); therefore, n = 60, except for thiamin n = 59, vitamin A n = 56, niacin n = 57, vitamin B_6 n = 58, vitamin B_{12} n = 50, iron n = 58, and zinc n = 59.

[b]Median [25th, 75th percentile] of the distribution of intakes.

[c]EARs were calculated from RNIs (FAO/WHO), using conversion factors (Allen, et al., 2006) except for iron, where values from IOM (2000) were used.

[d]Percent coverage of the RNI of the intakes of the children.

[e]Daily energy requirements were used (FAO, 2004).

[f]Recommended dietary allowance of the IOM used.

TABLE 4 Foods that contributed ≥5% to nutrient intake in the best diet pattern for at least five nutrients and the subfood groups they belong to

Subfood group	Food	Count of nutrients with contribution ≥ 5% to intake
Whole grains and products, unenriched/unfortified	Flour, millet, red	9
Nuts, seeds and unsweetened products	Groundnuts, raw	9
Whole grains and products, unenriched/unfortified	Flour, maize, white	8
Whole grains and products, unenriched/unfortified	Flour, maize, yellow	8
Vitamin C-rich vegetables	Cowpeas leaves	7
Fluid or powdered milk unfortified	Milk cow whole	7
Small whole fish with bones	Omena	6
Vitamin A-rich vegetables	Sukuma wiki	5
Other starchy plants	Potatoes, irish	5

consumption of ASFs is limited and consumption of plant-based foods is high (Bwibo & Neumann, 2003; Siekmann et al., 2003). Even though the community was largely a fishing community, fish was reserved for the market and not for consumption. A behaviour change communication campaign encouraging families to consume some of the fish could be a way to raise awareness in this particular population on importance of ASFs in the diets of the children.

With exclusion of zinc-fortified water, intakes of zinc, vitamin A, and folate remain inadequate. In order to improve the worst case scenario, further ways likely to improve zinc intake would be consuming more of the zinc-fortified water or zinc fortification of flour (Shah, Sachdev, Gera, De-Regil, & Peña-Rosas, 2016) or use of multiple micronutrient powders (Troesch et al., 2011). For vitamin A, alternative interventions and approaches beyond the foods that are already consumed by the children and approaches such as supplementation, food fortification and biofortification have to be explored in order to improve intake. Though the Government of Kenya has universal vitamin A supplementation programmes for all under 5-year-old children, national coverage has been shown to be low as 28% in 2014 (The World Bank, n.d.). Biofortification of plant foods with pro-vitamin A such as yellow sweet potato and yellow cassava is a promising approach that has been proven to improve vitamin A status in vulnerable groups (Brauw et al., 2013; De Moura et al., 2014), and recently in an efficacy trial in central Kenya (Talsma et al., 2016). The challenge will be to improve coverage of vitamin A supplementation, enforce and monitor vitamin A fortification of other foods, and scaling up of biofortification efforts.

The Optifood approach is a useful tool for analysing nutrient gaps in diet patterns and developing FBRs for improving nutrient adequacy in the diet. However, the process is dependent on the quality of the dietary recall data, the FCT used, assumed bioavailability of nutrients, and proposed RNIs. Although our analysis is based on the best

TABLE 5 Comparison of worst case scenario nutrient levels of seven individual alternative sets of FBR worst case scenario nutrient levels of diet of children 4–6 years old consuming zinc-fortified water in Kisumu, rural western Kenya, Kenya[a]

Analysis[b]	Protein %	Fat %	Calcium %	Vitamin C %	Thiamin %	Riboflavin %	Niacin %	Vitamin B-6%	Folate %	Vitamin B-12%	Vitamin A %	Iron %	Zinc %	Count ≥ 70% RNI
Module III Phase I (no recommendation)														
Best case scenario with zinc-fortified water	318	132	158	274	238	154	132	194	110	211	52	135	101	12
Best case scenario no zinc-fortified water	318	132	158	274	238	154	132	194	110	211	52	135	76	12
Worst case scenario with zinc-fortified water	144	41	13	7	105	38	39	82	28	15	2	56	66	3
Worst case scenario no zinc-fortified water	144	41	13	7	105	38	39	82	28	15	2	56	40	3
Module III Phase II worst case scenario nutrient levels for 8 single alternative sets of recommendations[b]														
Small whole fish 7 servings per week	180	45	71	8	107	43	52	86	28	133	2	61	71	6
Vit. C-rich vegetables 7 servings per week	151	41	31	105	111	53	46	92	41	15	5	74	66	5
Nuts, seeds unsweetened products 4 servings per week	144	72	13	7	107	64	39	83	40	15	2	56	68	4
Fluid milk unfortified 7 servings per week	157	49	40	11	105	73	39	82	28	49	12	56	67	4
Whole grain products 14 servings per week	144	41	13	7	113	40	41	90	28	15	2	57	67	3
Vit. A-rich vegetables 7 servings per week	147	41	21	58	112	38	47	90	28	15	12	59	66	3
Other starchy plants 7 servings per week	144	41	17	34	131	38	69	93	35	15	2	58	66	3

Notes. "Servings per week" refers to the number of averaged sized portions consumed per week. Alternative sets of recommendations selected at subfood group level.

[a]Values are expressed as percentage of recommended nutrient intakes (RNI).

[b]Module 3 was run with the fortified zinc water group.

available information at this time, for example, water intake was measured using the most reliable method obtained after comparing five in a pilot study (i.e., tally counter, 24-hr recall, graduated water jug, personal diary, and observation), the results are sensitive to the decisions made concerning the model parameters (Daelmans et al., 2013). Therefore, the decision process for input parameters should be clearly outlined for concluding and reproducibility purposes. We used the actual median daily drinking water intake derived from a more extensive surveillance of fortified drinking water quantity consumed. This ensured that a realistic quantity was modelled into the Optifood analysis. Also, the zinc content of the drinking water was regularly determined by own chemical analysis. The simulation of the contribution of zinc intake through water is thus close to a realistic setting. The bioavailability of zinc from fortified water was assumed to be 65.9%, a result of absorption studies conducted using stable isotopic zinc labels with the fortified water (Galetti et al., 2015). Although caregivers and children were strongly advised to consume the water away from meals, it is not known whether this was actually done. When consumed with a meal, zinc bioavailability from water is drastically lower and will be dependent on the phytic acid level in the diet (Galetti et al., 2015). With the use of the lower bioavailability level when modelling the same final FBRs, the percent RNI coverage of zinc was reduced from 87% to 66% in the worst case scenario. Depending on the bioavailability level chosen, our zinc adequacy might therefore be overestimated.

We selected for the modelling process foods consumed by 5% or more children as we assumed that these were the commonly consumed foods. This resulted in total 45 foods for input into the model. When modelling foods consumed by more than 10% of the children, the food list contained less foods (38 foods) and resulted in the identification of an additional problem nutrient (fat) in addition to folate, and vitamin A. Including less foods into the modelling may limit the options that Optifood analysis has for selection of foods, and as a result, more problem nutrients might be expected. Including foods consumed by <5% of the children might have increased the options but may decrease the feasibility of implementing recommendations as these foods are not commonly consumed. The choice of cut-off for frequently consumed foods therefore influenced the results, and the effect of such decisions on final recommendations should be further studied. We used the WHO/FAO RNI for zinc of 9.6 mg/day. An option would have been to use the IZINCG recommended dietary allowance, which is set at 5 mg/day (Brown et al., 2004). Using the latter cut-off would have made the diet sufficient, and zinc would not have been a problem nutrient. However, this sufficiency was not reflected by the high level of zinc deficiency in the study population. This may indicate that in our population, zinc requirements are elevated may be due to frequent diarrheal infections. Diarrhoea is known to deplete zinc stores in children (Castillo-Duran, Vial, & Uauy, 2015; UNICEF/WHO, 2009; Wapnir, 2000) and is a common infection

TABLE 6 Evaluation of the worst case scenario nutrient levels for the best combined alternative sets of FBR for the children 4–6 years old consuming zinc-fortified water in Kisumu, rural western Kenya, Kenya (diet with zinc-fortified water)[a]

Analysis	Protein %	Fat %	Calcium	Vit. C	Thiamin	Riboflavin	Niacin	Vit. B_6	Folate	Vit. B_{12}	Vit. A	Fe	Zn	Count of nutrients ≥ 70% RNI[b]
No recommendations_best case	318	132	158	274	238	154	132	194	110	211	52	135	101	12
No recommendations_worst case	144	41	13	7	105	38	39	82	28	15	2	56	66	3
Module III Phase III worst case scenario nutrient levels for best combined single alternative sets														
N4 + WG14 + VC7 + VA7 + F7	193	78	97	156	136	90	75	130	56	134	15	90	80	11
N4 + WG14 + VA7 + F7 + S7	186	77	83	85	159	75	99	133	50	134	12	78	80	11
N4 + VC7 + VA7 + F7 + S7	191	77	101	182	149	86	96	126	62	134	15	84	74	11
N4 + VC7 + M7 + F7 + S7	201	86	121	135	142	123	88	121	64	168	15	81	76	11
N4 + WG14 + VC7 + VA7 + M7 + F7	208	88	125	160	141	128	76	136	59	168	25	91	84	11
N4 + WG14 + VC7 + VA7 + F7 + S7	195	78	102	183	168	91	106	147	65	134	15	97	82	11
N4 + WG14 + VC7 + M7 + F7 + S7	211	88	121	136	165	130	99	143	68	168	15	95	86	11
N4 + WG14 + VA7 + M7 + F7 + S7	205	87	111	90	165	113	100	139	54	168	22	79	85	11
N4 + VC7 + VA7 + M7 + F7 + S7	205	86	129	186	149	123	96	131	64	168	25	84	77	11
N4 + WG14 + VC7 + VA7 + M7 + F7 + S7[c]	217	88	130	188	174	130	108	153	68[d]	169	25[d]	98	87	11

Notes. Recommendations include zinc-fortified water. F = small whole fish with bones 7 servings per week; M = fluid or powdered milk unfortified 7 servings per week; N = nuts, seeds, and unsweetened products 4 servings per week; S = other starchy plants 7 servings per week; VA = vitamin A-rich vegetables 7 servings per week; VC = vitamin C-rich vegetables 10 servings per week; WG = whole grain products unenriched unfortified 14 servings per week.

[a]Values are expressed as percentage of recommended nutrient intakes (RNI).

[b]Total number of nutrients > 70% RNI.

[c]Best optimized diet worst case scenario.

[d]Remained below 70% in final food-based recommendations (FBR).

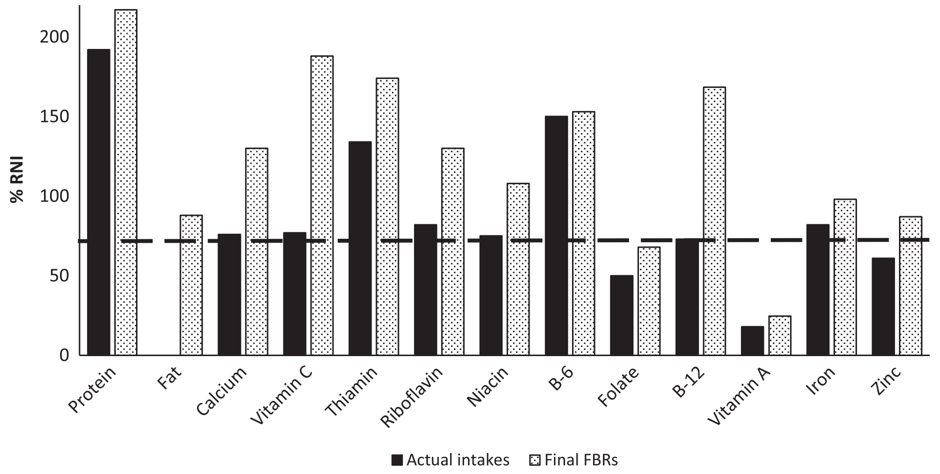

FIGURE 1 A comparison between the actual median nutrient intake levels of the Kenyan children aged 4–6 years with the final modelled diet (worst case scenario)

in Western Kenya (Adazu, 2005; Tornheim, 2010). Therefore, the use of the WHO/FAO RNI for zinc was considered to be more appropriate for our study population.

Data collection took place during the preharvest season, and results cannot necessarily be extrapolated to other seasons. The households mainly relied on own food production dependent on rain-fed agriculture, and seasonal variations in food availability and intake are expected (Brown, Black, & Becker, 1982; Nyambose, Koski, & Tucker, 2002; Willet, 1998). In general, there are fewer vegetables available in the preharvest season than in postharvest, and this, in our study area, is reflected by limited availability of vegetables such as pumpkin leaves (*Cucurbita* sp.), cowpeas (*Vigna unguiculata*), and sunnhemp (*Crotalaria brevidens*) but high availability of sukuma wiki (*Brassica* sp.), spider plant (*Gynandropsis gynandra*), amaranth (*Amaranthus* sp.), and nightshade (*Solanum nigrum*), (Guarini, 1997). Sukuma wiki was the most consumed vegetable in our study population and is in the subfood group of vitamin A-rich vegetables. However, even in the season of abundance, its consumption at the mentioned serving sizes did not ensure adequate vitamin A intake. A study conducted in rural Kenya found a deficit in vitamin A, riboflavin, and thiamin but no difference in energy, fat, protein, and niacin intake when preharvest intake was compared to postharvest intake (Kigutha, van Staveren, Veerman, & Hautvast, 1995). Conducting this study during the postharvest season would probably have resulted in selecting more vegetables and plant foods with higher serving sizes most likely yielding higher percent RNI coverage for vitamin A and folate. Comparative analysis using dietary intake data from different seasons would be required to understand how FBRs might change. In addition, it is important to emphasize that the data used to set the model parameters in Optifood originated from a limited area in the western part of Kenya and that the agro-ecological zone in which the study area is located is not representative for the whole of Kenya. Therefore, the extent to which the developed recommendations also apply to other areas in Kenya needs to be further assessed.

These recommendations are developed on the basis of the local dietary pattern through using the foods regularly consumed by the target population in observed portion sizes and frequencies, and as such are assumed to be realistic. However, as the extremes of the frequency distributions had to be used for some foods to reach optimal nutrient adequacy, the dietary recommendations may ask for substantial changes in the diets for a large part of the target group. Whether these changes are feasible, affordable, practical, and acceptable needs to be further studied with the target population to identify barriers and supporting factors that could encourage adoption of or lead to adaptation of the recommendations.

In conclusion, combining food-based dietary recommendations with zinc-fortified water using Optifood potentially improves nutrient adequacy of children in Kisumu West district, Kenya.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

PK, KB, VG, IB, DM, PA, and MBZ designed the research; PK EO, CS, HH, and VG conducted the study; KB, PA, IB, and DM supervised the field work; PK, CS, and HH analysed data; PK wrote the first draft of the paper; and all authors edited and approved the final version of the paper.

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