The potential contribution of yellow cassava to dietary nutrient adequacy of primary-school children in Eastern Kenya; the use of linear programming

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Abstract

Objective: Introduction of biofortified cassava as school lunch can increase vitamin A intake, but may increase risk of other deficiencies due to poor nutrient profile of cassava. We assessed the potential effect of introducing a yellow cassava-based school lunch combined with additional food-based recommendations (FBR) on vitamin A and overall nutrient adequacy using Optifood (linear programming tool).
Design: Cross-sectional study to assess dietary intakes (24 h recall) and derive model parameters (list of foods consumed, median serving sizes, food and food (sub)group frequency distributions, food cost). Three scenarios were modelled, namely daily diet including: (i) no school lunch; (ii) standard 5 d school lunch with maize/beans; and (iii) 5 d school lunch with yellow cassava. Each scenario and scenario 3 with additional FBR were assessed on overall nutrient adequacy using recommended nutrient intakes (RNI).
Setting: Eastern Kenya.
Subjects: Primary-school children (*n* 150) aged 7–9 years.
Results: Best food pattern of yellow cassava-based lunch scenario achieved 100 % RNI for six nutrients compared with no lunch (three nutrients) or standard lunch (five nutrients) scenario. FBR with yellow cassava and including small dried fish improved nutrient adequacy, but could not ensure adequate intake of fat (52 % of average requirement), riboflavin (50 % RNI), folate (59 % RNI) and vitamin A (49 % RNI).
Conclusions: Introduction of yellow cassava-based school lunch complemented with FBR potentially improved vitamin A adequacy, but alternative interventions are needed to ensure dietary adequacy. Optifood is useful to assess potential contribution of a biofortified crop to nutrient adequacy and to develop additional FBR to address remaining nutrient gaps.

Biofortification of staple foods is recognized as a sustainable food-based approach to reduce micronutrient deficiencies as it has the potential to substantially increase the micronutrient intakes of a population[1]. Biofortified yellow cassava, developed through conventional plant-breeding techniques, is a new staple food that is similar in use and nutritional content to white cassava but additionally contains substantially higher amounts of pro-vitamin A[2]. Yellow cassava could potentially increase vitamin A intake and reduce vitamin A deficiency,

especially in remote rural areas where other interventions face challenges to reach people in need of vitamin A[3,4].

Although yellow cassava is an excellent source for pro-vitamin A and energy, it is known to be generally poor in other nutrients such as Fe and Zn[5]. Children whose diets consist largely of cassava may be vulnerable to micronutrient deficiencies[6]. As diets in resource-poor environments often lack multiple micronutrients[7], the introduction of yellow cassava, even when only the replacement of white cassava is targeted, will require

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additional food-based dietary adaptations to fill the existing nutrient gaps in the diet. Also, yellow cassava might displace other staple foods in the diet, so promoting its consumption may inadvertently have a negative impact on dietary adequacy.

Optifood, a software program based on linear programming, was developed to formulate affordable, population-specific, food-based recommendations (FBR) based on current dietary practices and costs of food[8]. As these FBR are developed to resemble the local diet as closely as possible, they are more likely to be followed than more general guidelines that may deviate from local habits. 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 for high-risk populations and the extent to which these measures might contribute to its achievement[9,10]. To our knowledge, Optifood has not yet been used to inform biofortification programmes planning to promote the consumption of a biofortified crop with elevated levels of a single nutrient within a set of dietary recommendations. The advantages of using this mathematical modelling approach are that it objectively determines: (i) whether promoting a biofortified food, to improve dietary adequacy of one nutrient, might affect overall dietary adequacy by replacing important food sources of other nutrients; and (ii) the optimal set of FBR that need to be promoted in addition to the biofortified crop to ensure dietary adequacy at an affordable cost.

School feeding is an important and widespread educational intervention globally involving approximately 370 million school-aged children[11], an often-neglected group, providing an opportunity for micronutrient interventions in a controlled environment[12]. School feeding programmes are designed to support education and food security of children living in poverty, by increasing enrolment and reducing absenteeism and dropouts, and contributing to their learning through avoiding short-term hunger[13]. However, less attention is given to reducing or preventing micronutrient deficiencies[14]. In Kenya, school feeding programmes provide a school lunch generally comprised of a mixture of cooked maize and beans[15], referred to as *githeri*, a common dish regularly consumed in households. In Eastern Kenya, however, rural schoolchildren are documented to have high levels of anaemia, stunting and inadequate intakes of many key nutrients in addition to vitamin A[16]. Murphy *et al.* showed that *githeri* as a school lunch did not improve the dietary quality and micronutrient intakes of schoolchildren in Eastern Kenya[17]. The introduction of yellow cassava, currently grown experimentally in Eastern Kenya, into the school feeding programme could improve the vitamin A intakes of schoolchildren but additional food-based dietary recommendations would be needed to achieve overall nutrient adequacy of the diet given the nutrient profile of cassava.

In the present study, secondary dietary intake data collected in the framework of a yellow cassava efficacy trial[18] were used in Optifood to: (i) evaluate whether including yellow cassava in the school lunch would potentially improve vitamin A adequacy without having a negative effect on overall dietary adequacy compared with no school lunch or a standard school lunch; and (ii) identify additional FBR needed in a yellow cassava-based school lunch programme to improve adequacy of nutrients other than vitamin A at lowest cost.

Materials and methods

Study design

The present study was based on cross-sectional dietary intake data collected as part of an 18-week randomized controlled trial on the efficacy of yellow cassava in improving vitamin A status in primary-school children[18]. In that trial, cassava was served as a mid-morning snack of boiled white or yellow cassava to children aged 5–13 years from May to November 2012. The trial also provided a school lunch made of a mix of cooked maize and beans. Cross-sectional dietary intake data were collected to quantify food intake in and outside the school and used to define inputs to model (using linear programming) three scenarios for a 7 d best diet, namely a daily diet including: (i) no school lunch; (ii) a standard 5 d school lunch with cooked maize and beans; or (iii) a 5 d school lunch of cooked yellow cassava. The yellow cassava-based school lunch scenario was further optimized using nutrient-dense foods.

The original study was registered (clinicaltrials.gov: NCT01614483), approved by ethical committees at Kenyatta National Hospital in Nairobi, Kenya and Wageningen University in the Netherlands, and written consent was obtained from parents and children.

Participants

The original trial involved 342 children (5–13 years old) in three primary schools in Kibwezi District, Eastern Province, Kenya, who were selected by screening and ranking according to serum retinol-binding protein concentration and those at the lowest end of the distribution were selected for the trial. For the present modelling study, we selected all dietary intake data available of children between 7 and 9 years of age (*n* 150) as they represented the largest age group for which FBR could be made.

Nutritional status assessment

Blood sample collection

All venous blood samples were obtained from fasted children at the start of the trial by venepuncture. Samples for retinol analyses were shielded from light and processed under subdued light conditions. All blood samples were stored at 2–8°C until centrifuging and in liquid

nitrogen (−196°C) in Kenya, and at −80°C during transport to and storage at the laboratory of the Division of Human Nutrition in Wageningen, the Netherlands.

Blood analyses

Concentrations of retinol were measured by HPLC and described in detail elsewhere[18]. Serum concentrations of C-reactive protein, α_1-acid glycoprotein, serum ferritin, serum soluble transferrin receptor, serum vitamin B_{12} and serum Zn were measured at the Meander Medical Hospital, Amersfoort, the Netherlands on a Beckman Coulter UniCel DxC 880i analyser as per manufacturer's instructions. Hb was measured using a Celltac-α automated haematology analyser (MEK-6410K) in Makindu Hospital, Kenya, as per manufacturer's instructions.

Nutritional deficiency cut-off levels

Vitamin A deficiency: serum retinol concentration <0·7 µmol/l[19]; Zn deficiency: serum Zn concentration <9·9 µmol/l[20]; vitamin B_{12} deficiency: mild, serum vitamin B_{12} concentration <133 pmol/l and moderate or severe, serum vitamin B_{12} concentration <107 pmol/l[21]; anaemia: Hb concentration <115 g/l[22]; Fe deficiency: serum ferritin concentration <15 µg/l[22].

Weight and height

Weight and height were measured at baseline according to WHO guidelines[23] using a mechanical floor scale and a portable stadiometer (Seca, Hamburg, Germany). Anthropometric indices were calculated using WHO ANTHROplus software version 3.2.2 (www.who.int/childgrowth/software/en/). Stunting was defined as Z-score for height-for-age less than −2.

Inflammation

Inflammation was defined as C-reactive protein >5 mg/l and/or serum α_1-acid glycoprotein concentration >1 g/l[24].

Dietary intake assessment

Dietary intakes of children out-of-school were assessed using a quantitative multi-pass 24 h recall[25] with all days evenly distributed over the week. These data were collected, during a home visit in October 2012, by well-trained interviewers in weeks 13 to 16 of the trial. Primary caregivers, in the presence of the child, were asked to recall all the foods and drinks consumed in and outside the home (except for the school lunch) by their child during the preceding day and to describe ingredients and cooking methods of any mixed dishes. Duplicate amounts of all foods or beverages consumed or of ingredients used in the preparation of mixed dishes consumed were weighed to the nearest 2 g using a Soehnle electronic kitchen scale. When duplicates were not available in the household, amounts were estimated in household units, in volumes, as their general sizes (small, medium or large), or as their monetary value equivalents. The total volume of

each (mixed) dish cooked at the respondents' household and the volume of this dish specifically consumed by the child were measured to determine the proportion of the dish consumed by the child. This proportion was multiplied by the total amount of ingredients used in the preparation of the dish to determine the amount of ingredients consumed by the child. Standard recipes were generated to estimate grams of ingredients consumed from mixed dishes eaten outside the home by averaging three recipes of different vendors in the local area[26]. Conversion factors were developed to convert household units, volumes, sizes and monetary values to their gram weight equivalents. Food price data were also collected from three different markets/kiosks to calculate, for each food, its mean price per 100 g of edible food.

Cassava intake in the schools was recorded daily as the difference in the weight of the plate of each child before and after eating during the 18-week intervention period and median intake was calculated. Pro-vitamin A concentration of the yellow and white cassava was analysed[18]. To estimate the average serving size of the maize and beans dish given at schools, the cooks (n 3) were asked to provide a standard portion per school and median portion size was calculated.

Data preparation and analysis for Optifood

Data preparation

The 24 h recall data were organized with the nutrient calculation system Compl-eat version 1.0 (Wageningen University, Wageningen, the Netherlands) and the model parameters were defined by using Microsoft® Excel 2010, the statistical software package IBM SPSS Statistics version 21 and Microsoft® Access 2010. These parameters included: a list of non-condiment foods consumed by ≥5 % of the children; the serving size of each food defined as median serving size for all children who had consumed it; and minimum and maximum number of servings per week, for each food group and food subgroup, defined as the 5th and 95th percentiles, respectively, of serve counts. Average number of servings per week for each food group was defined as the 50th percentile. Maximum number of servings per individual food within a food subgroup was estimated based on the percentage of children consuming that food. For the school lunch with yellow cassava and with maize and beans, the minimum and maximum number of servings per week were set at five, assuming these foods would be provided as school lunch on 5 d/week. Prices per 100 g of edible food were used to estimate the average and 75th percentile cost of the observed daily diet. All modelled diets had to meet (and not exceed) the energy requirement for the target group, estimated using their mean body weight and the FAO/WHO/United Nations University algorithm for estimating energy requirements[27]. The FAO/WHO recommended nutrient intakes (RNI) were used for all nutrients, except Zn,

assuming 5 % bioavailability for Fe (18 mg/d)[28,29]. For fat, average requirement of 30 % of energy was used[30]. For Zn, the International Zinc Nutrition Consultative Group's RNI of 7 mg/d was used[31] reflecting low bioavailability and representing the average of two age groups.

Nutrient intake calculations were based on a food composition table developed specifically for the present study, using the national food composition table of Kenya[32] as primary source complemented with data from food composition tables from South Africa[33], Mali[34], East Africa[35], the International Minilist[36] and the US Department of Agriculture database[37]. US Department of Agriculture retention factors[38] were applied to raw ingredients and foods to account for nutrient losses during food preparation. Pro-vitamin A and retinol were converted into retinol activity equivalents[39]. Pro-vitamin A concentrations in yellow cassava are predominantly in the form of β-carotene and total β-carotene concentration of boiled yellow and white cassava was used as ana-lysed[18]. Conversion factors for β-carotene in cassava were conservatively assumed to be 7:1, based on a study in healthy Americans consuming yellow cassava[40].

Optifood analysis

All analyses were carried out with Optifood version 4.0.4.0, an approach based on linear programming to design population-specific FBR[8]. Three dietary scenarios were modelled: (i) daily diet comprising foods consumed exclusively at or outside the home but not in school; (ii) daily diet complemented with a school lunch of cooked maize and beans; and (iii) daily diet complemented with a school lunch of cooked yellow cassava. Optifood's Modules 1–3 were used in the analyses. Module 1 was run to ensure model parameters were generating realistic diets. Subsequently, for each of the three dietary scenarios, Optifood's Module 2 was run to develop two best diets: one creating the best diet within the average food pattern and one creating the best diet deviating from the average food pattern but constrained by the minimum and max-imum number of servings per week. The total number of nutrients achieving 100 % of the RNI in the best diet deviating from the average food pattern ('best food pattern diet') were counted per scenario and compared between scenarios to determine whether including yellow cassava in the school lunch would affect overall dietary adequacy compared with no school lunch or a standard school lunch.

In Module 3, using the model parameters of the yellow cassava-based school lunch scenario, twenty-six different diets were modelled of which thirteen were diets with the maximized content of one of thirteen nutrients ('best-case scenario', selecting the high-nutrient-dense foods within each food group to verify the highest possible nutrient intake) and thirteen were diets with the minimized content of one of thirteen nutrients ('worst-case scenario', includ-ing the low-nutrient-dense foods per food group to verify

the lowest possible nutrient intake). Module 3 was initially run without FBR constraints to identify problem nutrients. Problem nutrients are those that are <100 % of its RNI in the best-case scenario (i.e. when nutrient content is max-imized). Next, food groups with weekly servings above zero in the Module 2 best food pattern diet, and individual foods contributing at least 5 % to the intake of one of the nutrients, were selected. FBR were developed by incorporating the selected food groups and individual foods, individually and in combination, and were tested to identify sets of FBR that covered >70 % of the RNI for most nutrients. In the final phase of analyses, nutrient-dense foods that were consumed less frequently or in low quantities were incorporated in the FBR and tested in Module 3 to determine if they improved problem nutrient adequacy. These nutrient-dense foods were identified in two ways: (i) foods consumed by less than 5 % of children that had a relatively high content of at least one of the problem nutrients; and (ii) foods consumed by ≥5 % of children that contributed more than 20 % to the intake of the problem nutrients and for which an increase in current number of servings per week was assumed to be feasible. In a last step, FBR incorporating selected nutrient-dense foods were tested in Module 3 separately. The set of recommendations (worst-case scenario) that achieved >70 % of the RNI for most nutrients but stayed below the 75th percentile of daily diet cost was selected.

Results

Baseline characteristics

The children in our study were on average 8·5 years old with 27 % being stunted (Table 1). Thirty per cent of the children suffered from vitamin A deficiency, but almost none were Zn deficient (3 %). Vitamin B_{12} status was in general low, with 58 % of the children being mildly defi-cient and 37 % being moderately or severely deficient. The prevalence of anaemia was only 6 % but 36 % of the children were Fe deficient. Inflammation affected 20 % of our population.

Food intake

One hundred and fifty 24 h dietary recalls in total were used for data analysis and sixteen out of forty-eight non-condiment food items were consumed by more than 5 % of the children (Table 2). Foods most commonly consumed were maize, both as whole grains and flour, beans, onions, tomatoes and oil. Serving sizes in the diet varied from 4 g/d for onion to 165 g/d for maize flour. Most of these sixteen foods had serving sizes >10 g/d (n 13, 81 %). White sugar, oil and onion were consumed in small portion sizes (≤10 g/d). The median daily diet cost was 24 Kenyan Shilling (KES), ranging from 2 to 111 KES with the 75th percentile estimated at 38 KES/d.

Table 1 Nutritional status indicators in the study population of primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012

	Mean, *n* or median	SD, % or IQR
Background characteristics		
Age (years), mean and SD	8·5	0·9
Sex = girl, *n* and %	74	49
Anthropometrics		
BMI-for-age* *Z*-score, mean and SD	−1·4	0·9
Height-for-age* *Z*-score, mean and SD	−1·2	1·0
Children being stunted*, *n* and %	41	27
Micronutrient markers		
Serum retinol concentration (µmol/l), mean and SD	0·81	0·18
Vitamin A deficiency†, *n* and %	45	30
Serum Zn concentration (µmol/l), mean and SD	13·7	2·2
Zn deficiency‡, *n* and %	5	3
Serum vitamin B_{12} concentration (pmol/l), median and IQR	123	97–160
Vitamin B_{12} mild deficiency§,‖, *n* and %	84	58
Vitamin B_{12} moderate/severe deficiency‖,¶, *n* and %	54	37
Hb concentration (g/l), mean and SD	131	11
Anaemia**, *n* and %	9	6
Fe deficiency††, *n* and %	53	36
Inflammation‡‡, *n* and %	31	20

IQR, interquartile range (25–75th percentile).
*WHO 2006 reference population[23].
†Vitamin A deficiency: serum retinol concentration <0·70 µmol/l[19].
‡Zn deficiency: serum Zn concentration <9·9 µmol/l[20].
§Vitamin B_{12} mild deficiency: serum vitamin B_{12} concentration <133 pmol/l[21].
‖*n* 146 for vitamin B_{12} and Fe deficiency.
¶Vitamin B_{12} moderate/severe deficiency: serum vitamin B_{12} concentration <107 pmol/l[21].
**Anaemia: Hb concentration <115 g/l for children aged 5–11 years[22].
††Fe deficiency: serum ferritin concentration <15 µg/l and soluble transferrin receptor concentration >1·55 mg/l[22].
‡‡Inflammation: serum concentration of C-reactive protein >5 mg/l and/or α₁-acid glycoprotein >1 g/l[24].

Linear programming

In Module 1 for each scenario twenty realistic diets were generated and, hence, no changes in parameters were needed. In Module 2, only diet contents of protein, vitamin C and thiamin were above 100 % of the RNI for all three dietary scenarios in the best food pattern (Table 3). Furthermore, diet Zn and Fe contents achieved >100 % of the RNI in two scenarios: the maize and beans school lunch and the cassava school lunch. Only the cassava lunch achieved >100 % of the RNI in the Module 2 best food pattern for vitamin B_6. The daily cost of the three scenarios ranged from 34 to 38 KES. The yellow cassava Module 2 best food pattern achieved >100 % of the RNI for the highest number of nutrients (Table 3; six out of thirteen nutrients). Problem nutrients, being <100 % of the RNI in the Module 2 best-case cassava scenario, were fat, Ca, riboflavin, niacin, folate, vitamin B_{12} and vitamin A. A set of FBR was developed, including added fat 7 times/week, dairy products 7 times/week, grain and grain products 14 times/week, legumes 14 times/week, yellow cassava 5 times/week and vegetables 28 times/week. These recommendations ensured the worst-case scenario values for protein, vitamin C, vitamin B_6, Fe and Zn achieved >70 % of the RNI, but those of fat, Ca, riboflavin, niacin, folate, vitamin B_{12} and vitamin A remained less than 60 % of their RNI (Table 4). The nutrient-dense food items that contributed ≥20 % to the intake of the problem nutrients were oil for fat, milk for riboflavin and vitamin B_{12}, and kale/collard greens for vitamin A. Frequency of these foods were increased with 7 servings/week. In addition, the hardly consumed foods chicken, beef and small dried fish were incorporated as nutrient-dense foods, although consumed by only three, two and one child(ren), respectively, in the age group 7–9 years. Portion sizes were estimated as median grams of the foods consumed by children in the total study population (age group of 5 to 13 years). Small dried fish was consumed only three times by the 5–13-year-old children and therefore the average portion size was used instead of median. All six nutrient-dense foods (oil, milk, kale/collard greens, chicken, beef and small dried fish) were added at various frequencies, individually and in combination, to the yellow cassava diet with FBR and for each combination a new set of FBR was developed and tested (Table 4). The addition of beef and chicken increased the nutrient adequacy only of niacin to at least 70 % (78 % of the RNI) in the worst-case scenario. Small dried fish increased the nutrient adequacy for three nutrients to at least 70 % of the RNI: Ca, niacin and vitamin B_{12}. Beef and chicken were not combined with the dried fish because of negligible extra contribution of these foods to nutrient adequacy. Addition of five compared with two weekly servings of fish did not increase the number of nutrients achieving >70 % of the RNI, but would increase the daily cost of the diet. Also, the inclusion of more than five weekly servings of fish in the FBR would exceed the energy requirement.

Final food-based recommendations

The final set of FBR selected were: oil, 7 servings/week; dairy products, 7 servings/week; grain products, 14 servings/week; legumes, nuts or seeds, 14 servings/week; small dried fish, 2 servings/week; yellow cassava (provided as school lunch), 5 servings/week; and vegetables, 28 servings/week (Table 5). This set of FBR hypothetically ensures dietary adequacy at the population level for all nutrients except fat, riboflavin, folate and vitamin A. The increase of nutrient adequacy as a percentage of the RNI coverage of the optimized diet (yellow cassava diet with FBR with nutrient-dense foods) compared with the average food pattern without school lunch is shown in Fig. 1.

Discussion

We found that, compared with no school lunch or a school lunch with maize and beans, yellow cassava provided as a

Table 2 Food groups and foods used for modelling as consumed by the study population of primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012

	% of children consuming	Serving size* (g/d)	Min. servings† (per week)	Max. servings‡ (per week)	Cost§ (KES/100 g)
Added fats		0	7		
Oil, vegetable	73	9	0	7	20
Added sugars		0	7		
Sugar, brown	20	14	0	4	12
Sugar, white	13	9	0	3	12
Dairy products		0	7		
Milk, cow's, fresh, boiled	22	31	0	7	8
Grains & grain products		7	21		
Flour, maize, white	65	165	0	7	6
Flour, wheat, refined	14	97	0	5	7
Rice, refined	8	83	0	2	12
Maize, grains, white, dried	62	114	0	7	5
Legumes, nuts & seeds		0	14		
Beans, red, dried	36	38	0	6	10
Beans, mung, dried	5	48	0	1	10
Peas, pigeon, dried	24	52	0	5	8
Peas, cow, dried	8	54	0	2	7
Vegetables		0	28		
Onion, bulb, red	68	4	0	7	10
Tomato	62	30	0	7	5
Cabbage	30	91	0	7	3
Kale/collard greens	25	39	0	7	8
School lunches					
Composites (mixed food groups)					
Maize & beans meal	72	306	5	5	0
Starchy roots & other starchy plant foods					
Cassava, yellow‖	28	374	5	5	0
Nutrient-dense foods					
Meat, fish & eggs					
Small fish, dried	1	50	0	7	33
Beef	1	55	0	7	36
Chicken	2	45	0	7	49

*Values are median serving sizes of the raw edible portions based on 24 h recalls. Median serving sizes for chicken and beef as well as mean portion size for fish were from 5–13-year-old children.
†Minimum frequencies were values in the 5th percentile of distribution.
‡Maximum frequencies were values in the 95th percentile of distribution.
§Mean costs in Kenyan Shilling (KES) per 100 g of edible portion, estimated from three different kind of shops or markets during October 2012.
‖Contains 394 µg β-carotene per 100 g boiled (fresh weight) based on own analysis[18].

Table 3 Nutrient composition (as a percentage of the recommended nutrient intake (RNI)) of the three diets for the average* and the best† food pattern (Module 2) modelled using linear programming (Optifood) among primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012

	No school lunch		Maize & beans school lunch		Yellow cassava school lunch	
	Average food pattern* (% of the RNI)	Best food pattern† (% of the RNI)	Average food pattern* (% of the RNI)	Best food pattern† (% of the RNI)	Average food pattern* (% of the RNI)	Best food pattern† (% of the RNI)
Protein	240	245	217	250	194	226
Fat	45	43	49	44	55	50
Ca	42	55	37	56	45	64
Vitamin C	201	203	199	203	428	432
Thiamin	122	117	143	137	151	145
Riboflavin	38	46	48	61	37	50
Niacin	50	55	61	71	56	66
Vitamin B_6	69	73	85	95	137	147
Folate	45	49	46	64	43	60
Vitamin B_{12}	3	19	4	10	4	10
Vitamin A	17	19	17	19	47	49
Fe	97	94	94	100	115	122
Zn	95	99	98	113	89	104
Cost/d (KES)	35	38	28	34	29	34
No. of nutrients >100 % of the RNI	3	3	3	5	5	6

KES, Kenyan Shilling.
*Average food pattern = best diet within average food pattern closest to median food pattern of the population.
†Best food pattern = best diet deviating from average food pattern, but constrained by the minimum and maximum servings per week.

Table 4 Results for the yellow cassava diet without and with food-based recommendations (FBR) including nutrient-dense foods, modelled using linear programming (Optifood) among primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012

	Protein (% of the RNI)	Fat (% of the RNI)	Ca (% of the RNI)	Vitamin C (% of the RNI)	Thiamin (% of the RNI)	Riboflavin (% of the RNI)	Niacin (% of the RNI)	Vitamin B₆ (% of the RNI)	Folate (% of the RNI)	Vitamin B₁₂ (% of the RNI)	Vitamin A (% of the RNI)	Fe (% of the RNI)	Zn (% of the RNI)	Cost* (KES/d)
Yellow cassava diet without FBR														
Best-case scenario	236	58‖	65‖	432	158	51‖	67‖	148	61‖	10‖	49‖	131	106	37
Worst-case scenario	161	31	22	229	92	22	38	98	28	3	30	84	63	22
Yellow cassava diet with FBR†														
Worst-case scenario	219	49	58	432	125	43	57	130	56	10	49	121	87‖	33
Worst-case scenario results for nutrient-dense foods added to the yellow cassava diet with FBR‡														
FBR + oil 7 servings/week	213	65	61	432	136	48	63	141	59	10	49	118	136	34
FBR + milk 7 servings/week	222	51	64	433	129	51	58	134	58	15	51	120	128	35
FBR + kale/collard greens 7 servings/week	220	49	65	382	131	39	63	133	53	10	61	123	88	33
FBR + beef 2 servings/week	231	53	59	432	132	48	64	137	58	21	50	123	98	38
FBR + beef 5 servings/week	250	59	62	432	143	54	75¶	147	59	37	51	125	115	46**
FBR + chicken 2 servings/week	229	50	59	432	128	46	62	135	57	12	51	121	91	39**
FBR + chicken 5 servings/week	244	52	60	432	134	51	70¶	142	58	15	54	121	98	48**
FBR + small dried fish§ 2 servings/week	243	52	116¶	432	132	50	70¶	141	59	81¶	49	124	103	37
FBR + small dried fish 5 servings/week	283	58	205¶	432	143	60	89¶	159	62	188¶	49	131	127	44**
Best-case scenario results for best optimized yellow cassava diet														
FBR + small dried fish 2 servings/week	286	59	211	431	148	61	90	160	63	195	49	131	129	45**

RNI, recommended nutrient intake; KES, Kenyan Shilling.
*Cost of the diet with or without FBR.
†% of the RNI increased to at least 70 % after FBR were applied.
‡FBR: added fat, 7 servings/week; dairy products, 7 servings/week; grain and grain products, 14 servings/week; legumes, 14 servings/week; yellow cassava, 5 servings/week; and vegetables, 28 servings/week.
§Final set of FBR selected (best optimized diet).
‖Problem nutrients could not reach 100 % of the RNI in the best-case scenario.
¶% of the RNI increased to at least 70 % by adding the nutrient-dense food to the FBR.
**Daily cost raised above the 75th percentile.

school lunch can potentially improve vitamin A adequacy of the diet without lowering overall dietary quality. However, even though combining the yellow cassava school lunch with FBR improved the nutrient adequacy of the diet, it did not ensure adequate intakes of fat (50 % of the average requirement), riboflavin (55 % of the RNI), folate (60 % of the RNI) and vitamin A (47 % of the RNI).

Table 5 Food-based recommendations (FBR) developed in the yellow cassava school lunch scenario optimized with nutrient-dense foods and comparison with the average food pattern among primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012

Scenario with yellow cassava as school lunch	Average food pattern* (servings/ week)	With FBR† (servings/ week)	With FBR & optimized diet‡ (servings/week)
Added fats	7	7	7
Dairy products	0	7	7
Grains & grain products	7	14	14
Legumes, nuts & seeds	7	14	14
Meat, fish & eggs (as small dried fish)			2
Starchy roots & other starchy plant foods (as yellow cassava)	5	5	5
Vegetables	21	28	28

*Results of Module 2 best diet within average food pattern of yellow cassava school lunch scenario.
†Results of Module 3 analysis of yellow cassava school lunch scenario with FBR including foods consumed by ≥ 5 % of the children.
‡Results of Module 3 analysis of yellow cassava school lunch scenario with FBR including nutrient-dense foods consumed with low frequency or low quantity.

The low diversity of the foods in the monotonous diet (only sixteen different food items are consumed by more than 5 % of the children), the low frequency and the small quantity of foods rich in nutrients consumed is a major limiting factor in the modelling. This suggests it will be a challenge to cover the nutrient gaps by adapting the local diet without introducing new nutrient-dense foods and/or radically modifying current food consumption patterns.

Remarkably, vitamin A remained a problem nutrient in our analyses and even the diet with yellow cassava, rich in pro-vitamin A, covered only 49 % of the required vitamin A intake. Children selected for the present study represented the lowest end of the vitamin A status distribution in the area with 30 % vitamin A deficiency. The diets of these children may therefore represent those that are low in vitamin A-rich foods compared with diets of other schoolchildren, which may explain why their recommended nutrient intake could not be fulfilled. Collard greens/kale provided the largest contribution to vitamin A intake, but quantities consumed were small, and for carotenoids both the bioavailability and retention due to long cooking is low[41] leading to reduced intake of bioavailable vitamin A. In addition, we provided a conservative estimate of the potential increases in vitamin A intake as we used cassava varieties with an average β-carotene concentration of 5·4 μg/g (fresh weight) for raw cassava and 3·9 μg/g (fresh weight) for cooked cassava and applied a conservative conversion factor of 7:1. Another study found a higher impact of adding yellow cassava to
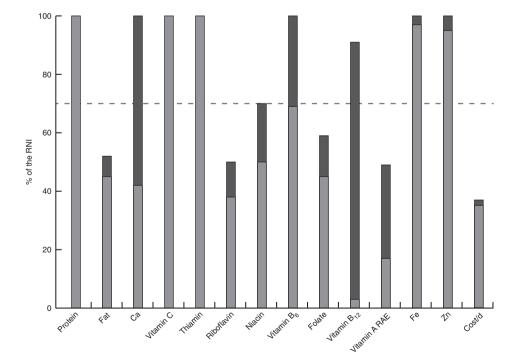

Fig. 1 Nutrient intake as a percentage of the recommended nutrient intake (RNI)* for the average food pattern (▨) and the optimized yellow cassava diet† (■) modelled using linear programming (Optifood) among primary-school children (*n* 150) aged 7–9 years, Eastern Kenya, May–November 2012. – – – – – represents 70 % of the RNI. *Values capped at 100 %; †final set of food-based recommendations selected (best optimized diet, in worst-case scenario). RAE, retinol activity equivalents

the diet but used different modelling assumptions regarding concentration, cooking method and intake quantity[4].

In our study, Fe and Zn were not identified as problem nutrients and this corresponds with the few children being Zn deficient (3 %). Although 36 % of the children had Fe deficiency, only 6 % had anaemia. Major food sources of Fe and Zn were maize, legumes and cassava, but animal foods were hardly consumed. For this reason, Fe bioavailability of 5 %, reflecting a vegetarian diet, was used[28], but the actual bioavailability of Fe in the diet may have been lower[42,43]. This might result in the identification of Fe as a problem nutrient. Also, food consumption studies among children 2–5 years old in Kenya and Nigeria showed that children consuming cassava as staple food are at risk for inadequate intake of Fe[6]. However, in our population cassava was not generally consumed as a staple food and other food sources ensured the adequacy of intake of Fe. Also, our study population is slightly older and the requirements for this older age group might be easier to achieve than for younger children.

The yellow cassava school lunch complemented with small dried fish ensured adequate dietary intake of Ca. Whole small fish including edible bones has proven to be a good source of Ca with a bioavailability comparable to that of milk[44]. However, in our population only one child in the age group 7–9 years had consumed small fish. The reason schoolchildren do not consume small fish or fish in general is unknown. Since the research site was far from any source of fish, availability, affordability and taste could be constraints to consumption and reduce feasibility of this FBR.

Our study has limitations that should be acknowledged. First, the measurement of habitual dietary intake of groups remains a major challenge in dietary intake assessment[26] and limitations of dietary data used as input for the Optifood analysis are related to weaknesses inherent to 24 h recalls. Major sources of systematic bias in the use of 24 h recall include under- or over-reporting of food intakes. To minimize bias, we used a systematic multiple-pass procedure and took precautions through training of interviewers, impromptu supervision to minimize reporting errors, proper calibration of instruments and random assignment of interviewers. Out-of-home food intake may have been omitted by mothers/caregivers and may have led to an underestimation of nutrient intake[45]. However, in this area, almost all meals are prepared and consumed at home and mothers/caregivers are fully involved in serving meals. Also, the presence of the children during the interviews meant they helped mothers/caregivers recall forgotten foods. Therefore, we believe that underestimation of food and thus nutrient intake was unlikely to have occurred.

We also assumed that the foods consumed out-of-school in our population reflected the habitual diet of schoolchildren, implicitly anticipating that children in general do not take food to school and that food provided in school would not affect the amount of food consumed at home. However, the school meal can be shared with other household members or can substitute (at least partly) food normally consumed in the house[46]. This sharing occurs for take-home rations where children take home a given quantity of food on a regular basis[47], but in our study the cassava lunch was consumed at school. Sharing may also happen between schoolchildren, but in our study children receiving the different lunches were physically separated. Substitution may also apply when meals are consumed at school, as in our study, and households opt to use the school meal as a substitute for food normally consumed at home as a cost-saving strategy. A study in rural Kenya did not find evidence that schoolchildren who received supplementary snacks at school reduced food intakes at home[48]. However, we observed during the preparation phase of the study that some children had taken food (consisting of maize and beans) from home to school for lunch, a habit they may have dropped when provided a school lunch. Our assumption that the food provided at school would not affect the food consumed outside school may have therefore led to a slight underestimation of the Optifood model parameters related to portion size and frequency of consumption, especially concerning maize and beans. As these foods are not major contributors to the nutrients identified as being in short supply, we assume a negligible effect on the identification of problem nutrients.

The cross-sectional survey captured a snapshot of dietary patterns and food cost/availability during only one agricultural season. As these vary per season, information on dietary intake in other seasons is necessary to evaluate applicability of our results through the year. Comparative analysis using dietary intake data from different seasons would be required to understand how FBR might change. It is also important to emphasize that the data used originated from a limited area in Kenya and are as such 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.

Finally, our results may be sensitive to assumptions used in defining model parameters. We used the International Zinc Nutrition Consultative Group's RNI[31], which are below those recommended by the FAO/WHO[28]. When we did a sensitivity analysis using the FAO/WHO's Zn RNI, Zn also became a problem nutrient for schoolchildren. This is not confirmed by the very low prevalence of Zn deficiency (3 %) in our population, indicating that the International Zinc Nutrition Consultative Group's RNI are likely the best to use. We assumed a low bioavailability of Fe (5 %) based on the high consumption of unrefined cereals and legumes, and low consumption of animal-source foods. Doing so, Fe intake was not detected as below 70 % of the RNI, even when low-nutrient-dense foods were used; assuming higher bioavailability would not change this finding. We included

only foods consumed by ≥5 % of the children: if we would have included foods consumed by ≥3 % of the children, the number of foods in the food lists would have been increased slightly, however frequency of consumption of these foods was low and therefore it is unlikely that these foods would be selected in the FBR. In addition, including infrequently consumed foods may decrease the feasibility of implementing recommendations.

Our study shows that providing yellow cassava in a school lunch programme can ensure nutrient adequacy of the diet in our study area for nine out of thirteen micronutrients when promoted within a set of FBR. However, proposed recommendations will require changes in the diet (such as the consumption of small dried fish) and also imply additional changes to the school meal programme. Optifood modelling is theoretical by nature and therefore consultations with local stakeholders are very important to determine whether these modifications to typical dietary behaviour are realistic and feasible[10] and recipes for the school meal programme incorporating these changes should be carefully developed and tested. However, even the best modelled diet could not meet the requirements for fat, riboflavin, folate and vitamin A. Additional interventions and solutions would be needed beyond promoting the consumption of nutrient-dense foods that are commonly consumed by the children to fully eliminate the risk of inadequate nutrient intakes in this population. Since the extent of the multiple micronutrient deficits in the modelled diets would be difficult to meet with a single intervention product, more biofortified crops could be introduced, or the introduction of yellow cassava could be integrated with approaches that encourage changes in the traditional diets as well as introduction of improved products such as fortified foods or improved nutrient supplements. Our study also showed that linear modelling of dietary intake data provides an excellent tool to evaluate and develop nutritional strategies for achieving better nutritional adequacy under local circumstances.

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