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Including calcium-fortified water or flour in modeled diets based on local foods could improve calcium intake for women, adolescent girls, and young children in Bangladesh, Uganda, and Guatemala

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Abstract

Adequate calcium intake is essential for health, especially for infants, children, adolescents, and women, yet is difficult to achieve with local foods in many low- and middle-income countries. Previous analysis found it was not always possible to identify food-based recommendations (FBRs) that reached the calcium population recommended intake (PRI) for these groups in Bangladesh, Guatemala, and Uganda. We have modeled the potential contribution of calcium-fortified drinking water or wheat flour to FBR sets, to fill the remaining intake gaps. Optimized diets containing fortified products, with calcium-rich local foods, achieved the calcium PRI for all target groups. Combining fortified water or flour with FBRs met dietary intake targets for adolescent girls in all geographies and allowed a reduction from 3–4 to the more feasible 1–2 FBRs. Water with a calcium concentration of 100 mg/L with FBRs was sufficient to meet calcium targets in Uganda, but higher concentrations (400–500 mg/L) were mostly required in Guatemala and Bangladesh. Combining calcium-fortified wheat flour at

400 mg/100 g of flour and the FBR for small fish resulted in diets meeting the calcium PRI in Bangladesh. Calcium-fortified water or flour could improve calcium intake for vulnerable populations, especially when combined with FBRs based on locally available foods.

KEYWORDS
calcium, dietary adequacy, food-based recommendations, fortification, fortified flour, fortified water, linear programming

INTRODUCTION

Globally, 3.5 billion people are at risk of inadequate calcium intake, and the majority are located in low- and middle-income countries (LMICs).[1] Ensuring adequate calcium intake leads to health benefits for all age groups, but specially for infants, children, and women during reproductive years.[2] Aside from the more studied impact on bone health, a growing body of evidence has demonstrated the impact of calcium on the reduction of preeclampsia and child health.[3,4] Taking into account the extent of inadequate calcium intake across multiple age groups in countries around the world and the widespread impacts on health outcomes, a population-based approach to improve calcium intake could redress current health disparities.[5]

Recommended calcium intakes can be difficult to reach with locally available foods. Using the Food and Agriculture Organization (FAO) of the United Nations food balance sheets from 145 countries, Kumssa et al. showed that the average amount of calcium provided by locally available foods is not enough to cover the population calcium needs in many LMICs.[5] Although these national-level data do not provide insights into the geographical and intrahousehold distribution of foods or focus on the most vulnerable populations, the analysis suggests that diets in these countries may not be able to supply adequate amounts of calcium.

Another paper in this special issue applied linear programming analysis (LPA) based on food consumption data of vulnerable target groups (12- to 23-month-old breastfed children, 4- to 6-year-old children, 10- to 14-year-old girls and nonpregnant, nonbreastfeeding women (NPNB) of reproductive age) from 10 geographic regions across rural Bangladesh and urban and rural Uganda and Guatemala. The analysis assessed whether calcium population reference intakes (Ca PRIs) could be met using optimized diets based on locally available foods, identified local calcium food sources, and simulated food-based recommendations (FBRs) to improve dietary calcium adequacy.[6] The best context-specific FBR sets could meet the calcium intake targets of 65% PRI in a calcium-minimized diet for NPNB women and 12- to 23-month-old breastfeeding children but not for the 4- to 6-year-old and 10- to 14-year-old girl groups. These findings indicate that either greater access, in terms of availability, prices, accessibility, and affordability,[7] to local calcium-rich foods or alternative food sources of calcium are needed to ensure that diets meet the PRI targets for all age groups. The results showed that FBRs to improve the dietary intake of calcium may not be enough alone to reach adequate levels in some LMICs; fortification could be an additional cost-effective approach to complement the promotion of local calcium-dense foods.[8,9]

Using individual food intake data from 24-hour recalls collected in five LMICs (Bangladesh, Uganda, Zambia, Lao People's Democratic Republic, and Argentina), previous studies have simulated the impact of population-based calcium fortification strategies using wheat flour and water as vehicles to improve dietary calcium intake.[10,11] These analyses estimated the gap between the recommended dietary calcium intake (estimated average requirement by the US Institute of Medicine) and the reported calcium intakes, and used these gaps to define fortification targets for each population assessed.[12] These analyses concluded that fortification interventions of either 156 mg of calcium per 100 g of flour or 500 mg of calcium per liter of water could decrease the prevalence of low calcium intake. Both simulations also were shown to be safe; simulated fortification indicated that the recommended calcium upper limit (UL) would be exceeded by less than 2% of the population assessed in Argentina, Bangladesh, Uganda, and Zambia.[10,11]

Flour fortification is a widely used strategy to improve micronutrient intake. Approximately 91 countries currently have policies mandating the fortification of wheat flour with micronutrients, including iron, iodine, folate, and vitamin A.[8,13] This presents opportunities to explore the possible addition of another micronutrient, such as calcium, to guidelines or standards. Although there are previous experiences of large-scale wheat flour fortification with calcium at levels between 156 and 200 mg/100 g of flour, calcium fortification of wheat flour is only mandatory in the United Kingdom and included in voluntary fortification specifications in very few countries.[13] To optimize the dietary intake impact of a fortification strategy, food vehicles should be selected according to the amount and percentage of the target population consuming that food. Wheat flour fortification would be less relevant in countries with low wheat flour intake, such as Uganda or Guatemala.[10]

Drinking water is a promising potential vehicle for fortification due to its widespread consumption as a beverage or in the preparation of foods.[11] Practically speaking, programmatic options for using water as a fortification vehicle depend on context and infrastructure and are only feasible if the population accesses water that could be treated, such as tap, well, or bottled water, rather than collected from natural sources.[11] These options, including national regulations for minimum mineral concentration in tap water or more localized interventions, such as home devices, or adding minerals as water is pumped from water wells or to clean water distributed in containers as part of water, sanitation, and hygiene (WASH) programs or commercial bottled water, require further investigation to explore potential cost, cost-effectiveness, and feasibility for specific locations.[11]

Drinking water has already been explored as a potential vehicle for fortification with micronutrients, such as zinc, iron, vitamin C, folate, and B vitamins in Kenya, Benin, Brazil, and Finland.[14–19] However, information on water intake among populations is scarce and the mineral concentration of water varies greatly by location. Specific details on the mineral composition of location-specific drinking water are limited and usually missing in chemical composition tables, which creates challenges to assess the contribution of water on mineral intake.[20,21] Calcium levels in drinking water regulations are usually expressed in terms of a maximum level of water hardness.[22,23] Calcium bioavailability in water is high, similar to or higher than in dairy products.[22] Bioavailability is improved when intake occurs in low doses, spread throughout the day, rather than in one dose. Using a consumer panel of 54 individuals from Argentina, a recent acceptability study of three different calcium salts added to bottled water found that the sensory threshold for taste was 587 ± 131 mg/L of water for calcium gluconate, 676 ± 186 mg/L for calcium lactate, and 291 ± 73 mg/L for calcium chloride.[21] Assuming it can be made safe and accessible and that sensory acceptability findings from this small sample in Argentina would apply in other countries, drinking water could potentially be a good alternative vehicle to improve calcium in the diet.[24–27]

This study, based on simulated diets using dietary data from the overall population, explored the potential of calcium-fortified wheat flour and water to complement the FBRs of local food sources of calcium in reaching the daily recommended Ca PRIs of four population groups (12- to 23-month-old and 4- to 6-year-old young children, adolescent girls, and NPNB women) across Bangladesh, Guatemala, and Uganda, where previous analysis showed that it was difficult or not possible to meet calcium intake targets using diets based on local foods alone. Specifically, the objectives were:

- Determine the ability of optimized diets that include calcium-fortified wheat flour or water to meet the Ca PRIs, without having a detrimental effect on the intake of other micronutrients.
- Estimate the contribution of combining calcium-fortified wheat flour or water with predeveloped full or reduced FBR sets on the Ca PRIs for one of these target groups in the context of local diets.
- Examine the extent to which including fortified flour or water alongside FBR sets could increase the risk that final optimized diets exceed the recommended daily UL for calcium intake.

METHODS

Source of food consumption data

Secondary food consumption data were analyzed in Optifood, a linear programming software that models diets based on local foods and dietary patterns to identify nutrient gaps and test FBRs.[28] As inputs to the LPA, we used the adult male equivalent (AME) to redistribute household-level food consumption data from publicly available household consumption and expenditure surveys (HCESs) and estimate individual-level *apparent* food consumption.[29–31] These data were selected, prepared, and analyzed in line with the best practices outlined by Adams et al.[32] We selected 10 geographic areas to represent diversity in terms of diets, food system characteristics, demographics, and malnutrition prevalence. These were urban and rural areas in both Central and North Uganda (four geographies), rural Sylhet and rural Barisal in Bangladesh (two geographies), and urban and rural areas in the Western Highlands and Dry Corridor of Guatemala (four geographies) (Table 1).

For this diet modeling exercise, we selected four target groups with high dietary calcium density requirements and of particular interest for nutrition programs in these geographic regions: breastfeeding children aged 12–23 months, preschool children aged 4–6 years, 10- to 14-year-old adolescent girls, and NPNB women of reproductive age.[6]

Estimation of input parameters for the LPA

The individual-level apparent food consumption data were used to develop input parameters for LPA in Optifood. Individual sets of input parameters, for each of the 40 combinations of geographies and age target groups, included a list of foods consumed by ≥5% of the relevant population, the average daily quantity of each food (g/day) when consumed, and an upper and lower limit on the number of servings per week for each food, food subgroup (FSG) and food group (FG) (10th and 90th percentiles of consumption—g/week). A daily quantity of breastmilk equivalent to 39% of energy requirements was included in food lists for the 12- to 23-month child target groups, assuming an energy content of 0.66 kcal/g.[33–35] The complete model parameters can be viewed in the supplementary tables from the previous paper.[6]

We matched food list items with energy and nutrient composition data from the 2012 Harvest Plus Food Composition Table (FCT) for Central and Eastern Uganda and published data on specific foods[36,37] (Uganda), the Nutrition Institute of Latin America and the Caribbean's (INCAP) FCT[38] (Guatemala), and the Indian National FCT and the USDA FCT[39,40] (Bangladesh).

Dietary reference values

The European Food Safety Authority (EFSA) PRIs were used as our dietary target levels for calcium and the other 10 micronutrients modeled (iron, zinc, vitamins A, C, B6, and B12, folate, thiamine, riboflavin, and niacin).[41,42] The EFSA PRIs target population-level recommended intake and are comparable to the WHO/FAO recommended nutrient intake (RNI) and the Institute of Medicine recommended dietary allowance[43]; further details on the selection of dietary reference values are provided in the previous paper.[6]

TABLE 1 Sources of food consumption data (household consumption and expenditure surveys), geographic regions, target groups selected, and analyses conducted as part of this simulation study.

Country	Food consumption data source	Geography	Location	Target group	Calcium-fortified water: Optimized diets (Mod 2)	Calcium-fortified water: Maximized diets (Mod 3)	Calcium-fortified water: FBR modeling (Mod 3)	Calcium-fortified wheat flour: Optimized diets (Mod 2)	Calcium-fortified wheat flour: Maximized diets (Mod 3)	Calcium-fortified wheat flour: FBR modeling (Mod 3)
Uganda	National Panel Survey Wave IV, 2013–2014, Uganda Bureau of Statistics	Central	Urban	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
			Rural	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
		North	Urban	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
			Rural	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
Bangladesh	Integrated Household	Barisal	Rural	BF young children	Yes	Yes	No	Yes	Yes	No
				Preschool children	Yes	Yes	No	Yes	Yes	No
				Young adolescent girls	Yes	Yes	Yes	Yes	Yes	Yes
				NPNB women	Yes	Yes	No	Yes	Yes	No
		Sylhet	Rural	BF young children	Yes	Yes	No	Yes	Yes	No
				Preschool children	Yes	Yes	No	Yes	Yes	No
				Young adolescent girls	Yes	Yes	Yes	Yes	Yes	Yes
				NPNB women	Yes	Yes	No	Yes	Yes	No
Guatemala	Living Conditions Survey (ENCOVI) 2015–2016	Western Highlands	Urban	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
			Rural	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
		Dry Corridor	Urban	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–
			Rural	BF young children	Yes	Yes	No	–	–	–
				Preschool children	Yes	Yes	No	–	–	–
				Young adolescent girls	Yes	Yes	Yes	–	–	–
				NPNB women	Yes	Yes	No	–	–	–

Abbreviation: FBR, food-based recommendation.
Notes: Mod 2 = Optifood analysis Module 2 in which diets meeting or coming as close as possible to 100% PRI for all modeled nutrients, within model parameters, are generated.
Mod 3 = Optifood analysis Module 3 in which diets with the highest possible calcium content, within model parameters, are modeled.
BF= breastfed young children, aged 12–23 months.
Preschool children = children aged 4–6 years.
Young adolescent girls = girls aged 10–14 years.
NPNB = nonpregnant and nonbreastfeeding women aged 18–50 years.

We adjusted iron and zinc requirements for unrefined, high-phytate diets, and adjusted niacin PRIs for energy targets.[43] We used the same locally adjusted energy levels used to develop AMEs and estimated protein requirements using the WHO/FAO/UNU algorithms and the average body weights.[44] ULs for calcium intake were taken from EFSA for NPNB women, and from the harmonized values proposed by Allen et al. for children, infants, and adolescents.[43]

Analysis of calcium-fortified flour and water in Optifood

As a next step in the development of calcium-promoting FBRs,[6] we analyzed calcium-fortified flour and water using LPA in Optifood to explore their potential contribution to complement these food-based approaches and further improve calcium intake.

TABLE 2 Calcium content of fortified water, recommended daily portions tested, and resulting total quantity of calcium (mg/day) tested.

Fortified vehicle	Calcium content of fortified vehicle	12–23 months child		4–6 years child		10–14 years girl		NPNB woman all	
		Portion g/day	Total Ca mg/day	Portion g/day	Total Ca mg/day	Portion g/day	Total Ca mg/day	Portion g/day	Total Ca mg/day
Wheat flour	156 mg/100 g (mandatory UK levels)	35	55	56	87	106	165	174	271
	200 mg/100 g (available on market in many countries)	35	70	56	112	106	212	174	348
	400 mg/100 g (estimated gap, deemed feasible)	35	140	56	224	106	424	174	696
Water	20 mg/L (simulating drinking water with low calcium content)	150	3	250	5	250	5	250	5
				500	10	500	10	500	10
		250	5	1000	20	1000	20	1000	20
				2000	40	2000	40	2000	40
	100 mg/L (simulating calcium concentration potentially compliant with drinking water regulations)	150	15	250	25	250	25	250	25
				500	50	500	50	500	50
		250	25	1000	100	1000	100	1000	100
				2000	200	2000	200	2000	200
	400 mg/L (simulating possible calcium concentrations in bottled water, in line with Ca intake gap estimates[10,20])	150	60	250	100	250	100	250	100
				500	200	500	200	500	200
		250	100	1000	400	1000	400	1000	400
				2000	800	2000	800	2000	800
	400 mg/L (simulating possible calcium concentrations in bottled water, in line with Ca intake gap estimates[10,20])	150	75	250	125	250	125	250	125
				500	250	500	250	500	250
		250	125	1000	500	1000	500	1000	500
				2000	1000	2000	1000	2000	1000

Abbreviation: NPNB, nonpregnant, nonbreastfeeding adult woman.

Input parameters: Calcium-fortified flour

We tested models of fortified flour in Bangladesh only as wheat flour was not commonly consumed by households in Uganda and Guatemala. Wheat flour was consumed by 21% of households on average across the two selected divisions of Bangladesh, compared to only 1.6% of households in Ugandan geographies and 3.6% in Guatemalan geographies (Table S1).[31,45,46] We used the average daily wheat flour portion sizes of each target group in Barisal and Sylhet to test three different levels of elemental calcium fortification of wheat flour (Table 2):

- 156 mg of calcium per 100 g of flour to simulate mandatory flour fortification levels from the United Kingdom[10];
- 200 mg of calcium per 100 g of flour to simulate calcium fortification levels recommended and available on the market in many countries[8]; and
- 400 mg of calcium per 100 g of flour, which represents the estimated gap in calcium intake between LMICs and high-income countries[1,47] and has been deemed practical to achieve using flour fortification.[2]

The daily portion sizes tested (35, 56, 106, and 174 grams per day for 12- to 23-month-olds, 4- to 6-year-olds, young adolescents, and adult women target groups) were much lower than the quantities of fortified flour that would exceed ULs for calcium intake for each target group (625–1923 g/day) (Table S2).

Input parameters: Calcium-fortified water

We tested four different daily water portion sizes and four different elemental calcium concentrations of drinking water (Table 2) in the context of local diets. As globally there is a paucity of data on water intake and the quantity of water intake was not reported in HCESs, we tested water quantities used in a previous simulation study: 250, 500, 1000, and 2000 mL per day for all target groups apart from 12- to 23-month-olds.[11] These quantities were also determined to be sufficiently lower than the amount of fortified water that would reach ULs for calcium intake for each target group (5000–7500 mL/day) (Table S2). For breastfed 12- to 23-month-olds, the largest portion tested was 250 mL of water per day.

Initial calcium concentration of water was also assumed, as it is not commonly reported in national chemical composition tables. We used a low calcium concentration water (20 mg/L) as an assumed scenario where water intake would be unlikely to contribute to significant calcium quantities in the diet. The alternative calcium levels were selected to provide a "low calcium" scenario and three different programmatic options:

- 20 mg/L to simulate drinking water with low calcium content
- 100 mg/L to simulate a calcium concentration level for drinking water potentially compliant with drinking water hardness regulations
- 400 and 500 mg/L to simulate higher calcium concentrations that could be added to water distributed in containers, such as bottled water or water provided by tanker trucks, and are in line with estimates of the calcium intake gap between population intakes and calcium requirements in LMICs[11,21]

Ability to meet calcium targets in the context of optimized diets, without any FBRs

We first ran Modules 2 and 3 (*identify* recommendations and *test* recommendations, as explained elsewhere[6,28,35]) in Optifood using food lists that contained calcium-fortified water and flour without any FBRs, meaning without *forcing* the consumption of any foods, fortified or unfortified.[6] This was to determine the extent to which Ca PRIs could be achieved in optimized diets based on local foods, and within realistic dietary patterns, if fortified water or fortified flour could be selected during diet optimization. We conducted separate analyses for each fortified product, fortification level/calcium concentration, and daily portion size. For each analysis, we included the fortified product in the Optifood food list, allowing up to seven daily portions to be selected in an optimized diet per week. We then ran the Module 2 analysis to identify the diet that would meet or come as close as possible to meeting 100% daily PRI of each modeled nutrient within the model parameters provided. Next, we examined the Module 3 calcium-maximized diet for each analysis, to obtain the food combination that would provide the highest possible calcium content, possibly to the detriment of reaching the PRI of other micronutrients. These are diets with the highest calcium content possible, given the target group-specific average energy requirements, the foods they apparently consumed (HCES survey data), median portion sizes (consumers), and upper and lower food, FSG, and FG frequency limits. If 100% of PRI was not met in the Module 3 calcium-maximized diets, it was unlikely that recommended calcium intakes could be met in diets containing the fortified product in question and local foods in accessible or acceptable quantities for the population. Alternatively, if 100% PRI was met in these Module 3 calcium-maximized diets, but was not met in the Module 2 best diet, this meant that the Ca PRI could be met using local foods and the fortified products, but only at the expense of meeting their PRIs of other nutrients.[48]

For both flour (Bangladesh only) and water, calcium concentrations or portion sizes were increased only if it was not possible to meet Ca PRIs using the lower calcium concentrations (flour and water) and portion sizes (water). If it was possible to meet Ca PRIs before adding any fortified products, flour or water were not included in incremental quantities/concentrations. Finally, the highest calcium concentration and portion sizes of flour (Bangladesh only) and water were tested for each target group to identify any potential risk that local diets containing these fortified products could exceed ULs for calcium. Where the daily calcium intake in the calcium-maximized diet of a population group exceeded 100% of the calcium UL for that target group, the next lowest portion size or concentration of a product was tested until the quantity of Ca in the calcium-maximized diet was below 100% of the UL.

Fortified flour and water in the context of FBRs

Next, we tested the fortified products within the context of FBRs, focusing only on the adolescent girl (10- to 14-year-old) target group due to particular vulnerability in terms of required calcium density and ability to meet the daily recommended calcium intakes using local foods.[6] We first assessed whether a diet with the lowest possible amount of calcium could meet adequacy targets using recommendations of consuming fortified water or flour, in different quantities/concentrations, in combination with the FBRs developed previously.[6,48] In this calcium-minimized diet, each combination of calcium fortification level and daily portion size option of fortified water or flour was modeled as a stand-alone recommendation as well as with every possible combination of the target group-specific FBRs from the previous study. The final options were compared for their ability to meet at least 65% of the daily recommended calcium PRI[35,48] in a calcium-minimized diet, which simulates the lower end of a nutrient's intake distribution within a population (Module 3).[35,48,49] In line with other published Optifood analyses, we considered any values over 65% of a nutrient's PRI in a calcium-minimized diet to be acceptable, as this would likely mean that a low proportion of the population would be at risk of inadequate intake of this nutrient.[35,48,49] Finally, we examined the highest %Ca PRI met combining FBRs for local foods and/or fortified products as a percentage of the UL for calcium for each relevant target group.

RESULTS

Ability to meet calcium targets in the context of optimized diets, without any FBRs

Fortified flour: Bangladesh

The inclusion of fortified flour meant that a diet could meet the 100% Ca PRI in the five Bangladesh target groups for which Ca PRI could not be met with local foods alone. Including wheat flour with 156 mg of calcium/100 g of flour allowed diets to reach 100% Ca PRI for breastfed 12- to 23-month-old children in Barisal and 10- to 14-year-old girls in Sylhet. However, fortified flour with 200 mg of calcium/100 g or 400 mg of calcium/100 g was needed to achieve 100% of the daily recommended Ca PRI for 4- to 6-year-olds and adolescent girls in

TABLE 3 Impact of allowing Optifood to include calcium-fortified wheat flour in optimized diets on whether 100% of calcium PRI could be met in Module 2 nutritionally best diets and Module 3 calcium-maximized diet for target groups in rural Barisal and Sylhet, Bangladesh.

Geography		Bangladesh							
		Rural Barisal				Rural Sylhet			
Fortified flour calcium content and quantity (g/day) tested	Daily flour portion tested (g/day)	BF young children	Preschool children	Young adol. girls	NPNB women	BF young children	Preschool children	Young adol. girls	NPNB women
Local foods only[a]	N/A	Pink	Brown	Brown	Light green	Pink	Light green	Pink	Light green
Fortified wheat flour (156 mg Ca/100 g)	35	Blue				Pink			
	56		Brown					Blue	
	106			Brown					
	174								
Fortified wheat flour (200 mg Ca/100 g)	35					Blue			
	56		Blue						
	106			Brown					
	174								
Fortified wheat flour (400 mg Ca/100 g)	35								
	56								
	106			Blue					
	174								

[a]Optimized combinations of local foods only.
Notes: BF = breastfed young children aged 12–23 months; Preschool children = children aged 4–6 years; Young adol. girls = girls aged 10–14 years; NPNB = nonpregnant and nonbreastfeeding women aged 18–50 years.
Color key:
Light green = 100% Ca PRI achievable using optimized diets based on local foods only (Ca fortification not modeled).
Blue = 100% Ca PRI achievable if fortified water/flour is included in optimized diet (at specified concentrations and portion sizes).
Pink = Only possible to meet 100% Ca PRI at the expense of meeting PRI of other nutrients.
Brown = Not possible to meet 100% Ca PRI.
White = Analysis not required/conducted.

Barisal and for 12- to 23-month-old children in Sylhet (Table 3). None of these optimized daily diets including fortified flour exceeded the daily recommended calcium ULs (Tables S2 and S3).

High calcium drinking water and fortified bottled water: All countries

Including calcium-fortified water in the modeled local diets increased the percentage of Ca PRI met in both the Module 2 nutritionally best diet and the calcium-maximized diet. For most 12- to 23-month-old breastfed children in Bangladesh and Guatemala, water containing 400 or 500 mg of calcium/L, mostly at portions of 150 mL/day, was required to meet 100% Ca PRI. For two 12- to 23-month-old target groups (Barisal, Bangladesh and urban Dry Corridor, Guatemala), 100% Ca PRI could also be met using high-calcium tap water containing 100 mg/L of calcium (Table 4).

For 4- to 6-year-old children in urban Central Uganda and urban Dry Corridor of Guatemala, 100% Ca PRI could only be met if 2000 mL/day of low calcium drinking water (20 mg/L), or 500 mL/day of higher calcium drinking water (100 mg/L) were consumed. For the same age group in Barisal, a larger portion (1000 mL/day) of higher calcium water or smaller portions (250 mL) of fortified bottled water would be needed to meet the calcium intake target (Table 4).

In the case of young adolescent girls in Sylhet, Bangladesh and rural Western Highlands, Guatemala, 100% Ca PRI could be met using drinking water with 100 mg of calcium/L with portions of 500 mL/day in Sylhet and 1000 mL/day in Western Highlands, as well as with smaller quantities of high-calcium bottled water. For the same age group in Barisal, 100% Ca PRI could only be met by providing fortified bottled water in larger portions (1000 or 500 mL/day for 400 and 500 mg water, respectively) (Table 4).

None of the calcium-maximized diets including high calcium waters for children or adolescents exceeded the daily recommended calcium ULs (Tables S2 and S3). The largest portion of fortified bottled water (400 or 500 mg calcium/100 mL) that needed to be modeled for 12- to 23-month-old breastfed children was 250 mL/day in urban Western Highlands of Guatemala, which, when included in a diet based on local foods, the highest calcium intake possible met 139.3% of PRI, which was equivalent to 20.9% of the UL for this target group. Two hundred fifty milliliters was also the largest portion of fortified bottled water needed to meet calcium targets for 4- to 6-year-old children, which, in a calcium-maximized diet, would be equivalent to 29.5%–38.8% of the calcium UL. Alternatively, larger (but likely difficult to promote) portions of 2000 mL/day of fortified bottled water met 220%–253% of the PRI for 4- to 6-year-old children, which was equivalent to 59%–68% of the 3000 mg/day UL for this target group. For 10- to 14-year-old girls, calcium-maximized diets including 250 mL daily portions of the highest concentration bottled water were equivalent to 33%–57% of the calcium UL where modeled. In Barisal, where 1000 mL of fortified bottled water was needed to meet 100% Ca PRI, calcium-maximized diets reached 45% of the UL. The largest portion of 2000 mL/day of fortified bottled water met 159%–237% of the PRI for 10- to 14-year-old girls, which was equivalent to 61%–91% of the 3000 mg/day UL for this target group (Table S3).

Optimized diets for all of the NPNB adult women target groups in Uganda, Guatemala, and Bangladesh were able to meet the Ca PRI using local foods only. However, as this target group had the lowest UL of 2500 mg/day, we also modeled diets containing fortified products at the largest daily portion sizes and highest calcium concentrations to assess the extent to which calcium-maximized diets based on local foods and large portion sizes of fortified products would approach the calcium UL.[42] The combination of optimizing the content of local foods to provide the highest possible calcium content (calcium-maximized diet) and a large portion of 2000 mL/day of 500 mg Ca/L fortified bottled water reached 106%–136% of UL for the NPNB women target groups. Calcium-maximized diets including 2000 mL/day of 400 mg Ca/L bottled water exceeded the UL (108%–128% UL) for NPNB adult women target groups in Uganda and Guatemala, but not Bangladesh (Table S3). Diets

TABLE 4 Impact of allowing Optifood to include calcium-fortified water in optimized diets on whether 100% of calcium PRI could be met in Module 2 nutritionally best diets and Module 3 calcium-maximized diets.

Geography: Uganda

Water calcium concentration and quantity (mL/day) tested		Central Urban BF young children	Central Urban Preschool children	Central Urban Young adol. girls	Central Urban NPNB women	Central Rural BF young children	Central Rural Preschool children	Central Rural Young adol. girls	Central Rural NPNB women	North Urban BF young children	North Urban Preschool children	North Urban Young adol. girls	North Urban NPNB women	North Rural BF young children	North Rural Preschool children	North Rural Young adol. girls	North Rural NPNB women
Local foods only[a]	N/A	Light green	Brown	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green	Light green
Water with 20 mg Ca/L	150																
	250		Brown														
	2000		Blue														
Fortified water (100 mg Ca/L)	150																
	250		Brown														
	500		Blue														
	1000																
Fortified water (400 mg Ca/L)	150																
	250		Blue														
	500																
	1000																
Fortified water(500 mg Ca/L)	150																
	250		Blue														
	500																
	1000																

Geography: Bangladesh

Water calcium concentration and quantity (mL/day) tested		Barisal Rural BF young children	Barisal Rural Preschool children	Barisal Rural Young adol. girls	Barisal Rural NPNB women	Sylhet Rural BF young children	Sylhet Rural Preschool children	Sylhet Rural Young adol. girls	Sylhet Rural NPNB women
Local foods only[a]	N/A	Pink	Brown	Brown	Light green	Pink	Light green	Pink	Light green
Water with 20 mg Ca/L	150	Pink				Pink			
	250	Pink	Brown			Pink		Pink	
	2000		Brown	Brown				Blue	
Fortified water (100 mg Ca/L)	150	Pink				Pink			
	250	Blue	Brown	Brown				Pink	
	500		Brown	Brown				Blue	
	1000		Blue	Brown					
Fortified water (400 mg Ca/L)	150	Blue				Blue			
	250		Blue	Brown				Blue	
	500			Brown					
	1000			Blue					
Fortified water(500 mg Ca/L)	150	Blue				Blue			
	250		Blue	Brown				Blue	
	500			Brown					
	1000			Blue					

Geography: Guatemala

Water calcium concentration and quantity (mL/day) tested		Western Highlands Urban BF young children	Western Highlands Urban Preschool children	Western Highlands Urban Young adol. girls	Western Highlands Urban NPNB women	Western Highlands Rural BF young children	Western Highlands Rural Preschool children	Western Highlands Rural Young adol. girls	Western Highlands Rural NPNB women	Dry Corridor Urban BF young children	Dry Corridor Urban Preschool children	Dry Corridor Urban Young adol. girls	Dry Corridor Urban NPNB women	Dry Corridor Rural BF young children	Dry Corridor Rural Preschool children	Dry Corridor Rural Young adol. girls	Dry Corridor Rural NPNB women
Local foods only[a]	N/A	Pink	Light green	Light green	Light green	Pink	Light green	Pink	Light green	Pink	Brown	Light green	Light green	Pink	Light green	Light green	Light green
Water with 20 mg Ca/L	150	Pink				Pink				Pink				Pink			
	250	Pink				Pink				Pink	Brown			Pink			
	2000							Pink			Blue						
Fortified water (100 mg Ca/L)	150	Pink				Pink				Blue				Pink			
	250	Pink				Pink		Pink			Brown			Pink			
	500							Pink			Blue						
	1000							Blue									
Fortified water (400 mg Ca/L)	150	Pink				Blue				Blue				Blue			
	250	Blue						Blue			Blue						
	500																
	1000																
Fortified water(500 mg Ca/L)	150	Pink				Blue				Blue				Blue			
	250	Blue						Blue			Blue						
	500																
	1000																

[a]Optimized combinations of local foods only.

Notes: BF = breastfed young children aged 12–23 months; Preschool children = children aged 4–6 years; Young adol. girls = girls aged 10–14 years; NPNB = nonpregnant and nonbreastfeeding women aged 18–50 years.

Color key:

Light green = 100% Ca PRI achievable using optimized diets based on local foods only (Ca fortification not modeled).

Blue = 100% Ca PRI achievable if fortified water/flour is included in optimized diet (at specified concentrations and portion sizes).

Pink = Only possible to meet 100% Ca PRI at the expense of meeting PRI of other nutrients.

Brown = Not possible to meet 100% Ca PRI.

White = Analysis not required/conducted.

including local foods and 1000 mL/day of 500 or 400 mg Ca/L fortified bottled water did not exceed the calcium UL in the urban and rural Dry Corridor of Guatemala and rural Central and urban and rural Northern Uganda. However, for urban and rural Western Highlands Guatemala and urban Central Uganda, this portion size exceeded the UL. When a lower portion size of 500 mL/day of the 400 or 500 mg/L fortified bottled water was modeled in calcium-maximized diets with local foods for these target groups, the calcium UL was not reached (Table S3).

Fortified flour and water in the context of FBRs

Fortified flour: Bangladesh

Table 5 displays the results of testing calcium-fortified flour at different fortification levels (156, 200, and 400 mg of calcium/100 g) as FBRs for the young adolescent girl target groups from the two geographies in Bangladesh. It was not possible to meet at least 65% of Ca PRI in any of the calcium-minimized diets using an FBR of fortified flour alone, at any fortification level. However, when combined with other FBRs, it became possible to meet 65% PRI in the calcium-minimized diet using 200 mg/100 g concentration in Barisal and 400 mg/100 g in Barisal and Sylhet. Finally, the different fortified flour FBRs were tested with individual other FBRs to identify whether reduced FBR sets could be promoted. It was possible to meet at least 65% Ca PRI in the calcium-minimized diet for just one of the combinations tested, which was using a recommendation for a daily intake of 400 mg/100 g calcium-fortified flour and five portions per week of small fish.

Fortified water: All countries

Table 6 and Table S4 present the results of combining the original best sets of local food FBRs for young adolescent girls for each geography (from another paper in this special issue)[6] with different quantities of water (250, 500, 1000, and 2000 mL/day) with increasing calcium concentrations (20, 100, 400, and 500 mg Ca/L). In Uganda and the urban Dry Corridor of Guatemala, it was possible to meet the target of at least 65% of the Ca PRI in the calcium-minimized diet with a set of FBRs based on local foods. However, in Bangladesh and in the urban and rural Western Highlands and the rural Dry Corridor of Guatemala,

TABLE 5 Percentage of calcium population recommended intake (PRI)–met diets modeled to provide the minimum calcium content possible, given model parameters, using different combinations of food-based recommendations and fortified flour for 10- to 14-year-old girls in Bangladesh.

Possible to meet the target of >65% Ca PRI in minimized diet	FBR details (food subgroup and number of portions per week)	Flour Ca content mg/100 g	Daily portion (g)	% Ca PRI met in the minimized Ca diet for young adolescent girls	
				Barisal	Sylhet
With FBRs	GLV 7/Milk 6/Small fish 5	N/A	N/A	51.2	48.1
With FBRs and flour	GLV 7/Milk 6/Small fish 5	156	106	63.7	58.2
		200	106	67.7	62.3
		400	106	86.2	80.7
With reduced FBRs and flour	Small fish 5	156	106	44.1	44
		200	106	48.2	48.1
		400	106	66.6	66.5
	Milk 6	400	106	52.4	50.8
	GLV 7	400	106	48.6	43.2
	GLV 7/Milk 6	400	106	60.3	54.1
With flour only	Flour 7	156	106	18.2	17.4
	Flour 7	200	106	22.3	21.5
	Flour 7	400	106	40.7	39.9

Abbreviations: FBR, food-based recommendation; GLVs, green leafy vegetables.

it had not been possible to identify a set of FBRs within the observed dietary patterns that would meet the calcium target.[6] It was possible to achieve 65% of the Ca PRI, for young adolescent girls in both Bangladesh geographies when 500 mL/day of 400 mg/L calcium water was modeled with the best FBR set (Table 6). In urban and rural Western Highlands and rural Dry Corridor of Guatemala, it was not possible to achieve 65% of the Ca PRI until a larger portion of 1000 mL/day of 400 mg/L Ca water was modeled with the best FBR set (Table 4). Alternatively, the Ca target could also be met using a lower portion (500 mL/day) of higher concentration (500 mg/L) water in the rural Dry Corridor of Guatemala.

Moreover, for all adolescent target groups in the three countries, it was possible to reduce the sets of recommendations from 3–4 to two FBRs if fortified water was also included. For all Ugandan target groups, at least 65% PRI was met in the calcium-minimized diets when 500 mL/day of high calcium tap water (100 mg/L) was included alongside FBRs to consume six portions of green leafy vegetables (GLVs) and seven portions of small fish per week (Table S4A). For the two Bangladesh target groups, a greater portion size and calcium concentration were required; 65% PRI was only met in calcium-minimized diets in which 1000 mL/day of water containing 400 mg/L calcium was included alongside FBRs to consume either seven weekly portions of GLVs and five portions of small fish or six portions of milk and five portions of small fish (Table S4B). In the urban and rural Guatemalan Dry Corridor, 400 mg/L water was also required, alongside FBRs to consume GLVs and maize tortillas; a daily portion of 500 mL was sufficient in the urban area, whereas 1000 mL would be required in rural areas to meet at least 65% PRI in calcium-minimized diets. Lastly in the Western Highlands of Guatemala, 1000 mL/day of the highest concentration calcium-fortified bottled water was required to reduce the recommendations to just two FBRs (Table S4C).

Finally, each proposed water quantity and calcium concentration was tested as a stand-alone recommendation. Across all geographies, it was only possible to meet at least 65% of the Ca PRI in the calcium-minimized diet when a large, likely difficult to promote, quantity of 2 L/day of bottled water (400 or 500 mg/L) was modeled (Table 5).

Calcium ULs were not exceeded in the Module 3 calcium-maximized diet that combined calcium-fortified products with FBRs for young adolescent girls (Tables S4A–C). In Uganda and Guatemala, where there were more calcium-rich food sources, the calcium-maximized diets met 85%–90.9% of the calcium UL when 2000 mL of the highest concentration calcium bottled water (500 mg/L) was modeled as a recommendation (Tables S4A and C). Conversely, modeling this quantity of bottled water reached 61% and 73% of the calcium UL in the two Bangladesh target groups (Table S4B). When FBRs were combined with 1000 mL/day of bottled water (400 or 500 mg calcium/L), the highest % UL reached was 71.5% in Guatemala and 52.2% in Bangladesh (Tables S4B and C).

DISCUSSION

This study shows that calcium-fortified wheat flour or water could improve the calcium content of local diets without risking exceeding the recommended calcium ULs. Fortified flour was tested in the context of the diets of target groups in Bangladesh to meet the 100% Ca PRI.

TABLE 6 Summary of results for food-based recommendation (FBR) testing with water.

Possible to meet target of >65% Ca PRI in minimized diet	Water Ca content (mg/L)	Daily water portion (mL)	% Ca PRI met in the minimized Ca diet for young adolescent girls									
			Central Uganda		Northern Uganda		Bangladesh		Western Highlands		Dry Corridor	
			Rural	Urban	Rural	Urban	Barisal	Sylhet	Rural	Urban	Rural	Urban
With best set of 3–4 FBRs only	N/A	N/A	76	77.8	89.1	78.2	51.2	48.1	30.7	37.7	45.9	65
With best set of 3–4 FBRs and Ca-fortified water	100	500	78.2	80	91.3	80.4	53.9	51.9	32.9	39.8	48.1	67.1
		1000	80.3	82.1	93.4	82.5	58.3	56.8	35.1	42	50.3	69.3
	400	500	84.7	86.5	97.8	86.9	67	65.4	48.2	55.1	63.3	82.3
		1000	93.4	95.2	106.5	95.6	84.4	82.8	65.6	72.4	80.7	N/A
	500	500	N/A	N/A	N/A	N/A	71.3	69.8	52.5	59.4	67.7	N/A
		1000	N/A	N/A	N/A	N/A	N/A	N/A	74.3	81.1	89.4	N/A
With reduced set of two FBRs and Ca-fortified water	100	500	66.2	67.7	76.2	71.1	N/A	N/A	30.2	33.2	38.4	53.1
	400	500	70.5	72.1	80.6	75.5	55.3	54.6	42	46.2	51.4	66.1
	400	1000	79.2	80.8	89.3	84.2	72.7	72	60.7	63.6	68.8	92.2
	500	1000	N/A	N/A	N/A	N/A	N/A	N/A	69.4	72.3	N/A	N/A
With Ca water only	20	250	1.9	2.3	2.2	3.2	4.7	3.9	6	4.3	3.6	3.9
		500	2.4	3.1	2.7	3.6	5.1	4.4	6.4	4.8	4	4.3
		1000	3.2	4	3.5	4.5	6	3.5	7.3	5.7	4.9	5.2
		2000	5	5.7	5.3	6.2	7.7	7	9	7.4	6.7	6.9
	100	250	3.7	4.4	4	4.9	6.4	5.7	7.7	6.1	5.3	5.6
		500	5.8	6.6	6.1	7.1	8.6	7.8	9.9	8.3	7.5	7.8
		1000	10.2	10.9	10.5	11.4	12.9	12.2	14.3	12.6	11.9	12.2
		2000	18.9	19.6	19.2	20.1	21.6	20.9	23	21.3	20.6	20.9
	400	250	10.2	10.9	10.5	11.4	12.9	12.2	14.3	12.6	11.9	12.2
		500	18.9	19.6	19.2	20.1	21.6	20.9	23	21.3	20.6	20.9
		1000	36.3	37	36.6	37.5	39	38.3	40.3	38.7	38	46.9
		2000	71.1	71.8	71.4	72.3	73.8	73.1	75.1	73.5	72.7	73
	500	250	12.4	13.1	12.7	13.6	15.1	14.4	16.4	14.8	14	14.3
		500	23.2	23.5	23.5	24.5	26	25.2	27.3	25.7	24.9	25.2
		1000	45	45.7	45.3	46.2	47.7	47	49	47.4	46.7	46.9
		2000	88.4	89.2	88.7	87.7	91.2	90.5	92.5	90.9	90.1	90.4

Note: Percentage of calcium population recommended intake (Ca PRI) met in diets modeled to provide the minimum calcium content possible, given model parameters, that included recommendations to consume local food sources of calcium and/or calcium-fortified water.

Fortification levels of 400 mg of elemental calcium per 100 g of flour were required for young adolescent girls' diets in Barisal to achieve the 100% Ca PRI, while lower levels of 200 or 156 mg/100 g were sufficient for younger children. Other Optifood analyses have concluded that it is harder to reach the Ca PRI of specific nutrients using local foods without the inclusion of fortified flour, rice, and other staple foods or complementary feeding products, specifically for iron among urban Egyptian women[50]; for zinc and iron among infants and young children (IYC) across Northern Kenya[48]; for calcium, zinc, and iron for IYC in Indonesia[51] and Cambodia[52]; and for vitamins B1 and B3, folate, and iron for IYC in Colombia.[53]

Fortified water was simulated in the diets of target groups, respectively, of Bangladesh, Guatemala, and Uganda to meet the Ca PRI. For 12- to 23-month-old breastfed infants, a very small daily portion of 150 mL of a bottled water containing 400 mg of calcium/L was sufficient to achieve the Ca PRI. For 4- to 6-year-old children and most young adolescent girl target groups, daily portions of 0.5–1 L of a high-calcium drinking water containing 100 mg calcium/L were sufficient. None of these diets exceeded the daily recommended calcium ULs.

The simulation of a calcium-maximized diet of NPNB adult women based on the recommendation of consumption of local foods to improve calcium intake was enough to reach the Ca PRI; however, we simulated scenarios to assess what portions of different fortification levels of water would exceed the calcium UL. All calcium-maximized diets that included 2000 mL/day of water containing 500 mg/L of calcium exceeded the calcium UL. Furthermore, calcium-maximized diets that included 1000 mL/day of the same fortified water exceeded the calcium UL in five of the 10 geographies. Alternatively, diets containing smaller portions of 500 mL/day of high-calcium water did not exceed the UL, indicating that providing calcium-fortified water at lower fortification levels or portion sizes would probably not risk exceeding the UL. It is important to note that the simulated diets exceeding the calcium UL were calcium-maximized diets, which are optimized to identify the combination of local foods, in combination with the added fortified product, that would provide the highest possible content of calcium. These diets are modeled within parameters obtained from the population food consumption data; however, they deviate from average consumption patterns and are unlikely to be consumed by many individuals in the population groups. Furthermore, these final maximized calcium contents consist of calcium from the modeled portion of fortified water and an optimized selection of locally available, unfortified foods, rather than the convergence of fortified water with supplements or other fortified products. Additionally, studies from the United States and European populations have indicated that calcium intakes among high consumers are often close to or above the UL.[53] The European Food Safety Advisory group concluded that there is no evidence of long-term calcium intake from foods and supplements increasing the risk of nephrolithiasis, cardiovascular disease, or prostate cancer, and that information from randomized controlled trials with intakes of 2.5 g of calcium a day is tolerated without adverse effects.[10,54,55]

Given that the reported intake of calcium among members of the studied population groups is generally very low in Uganda and Bangladesh, it may be necessary to combine more than one strategy to meet the Ca PRI, in this case, the provision or promotion of high-calcium-fortified water alongside the promotion of FBRs featuring high-calcium, local foods.[11,56,57] Capping any provision or promotion of high-calcium (≥400 mg/L) drinking water at 1000 mL/day for adult women could help in reducing the risk of consumption above the calcium UL in other areas where baseline calcium consumption is not low. The calcium ULs used were consistent across gender groups (i.e., 3000 mg/day for adolescents and 2500 mg/day for adults); as such, it is not expected that there would be an additional risk of exceeding ULs for adolescent boys or adult men, if modeled. However, given the lower calcium ULs for women and men aged over 50 years (2000 mg/day), it will be important to consider the risk of excess intake for these target groups. Moreover, further analysis should also consider the potential of meeting recommended calcium intakes for other target groups, such as adolescent boys, men, and older adults, using calcium-fortified water, as well as the risk of exceeding the calcium UL for other groups in the population, before designing fortification programs in any setting.

Combining calcium-fortified flour or water with targeted messaging around the consumption of calcium-rich local foods could improve calcium intake for vulnerable population groups. Adolescent girls' lower calcium content diets (calcium-minimized diets) reached the target of 65% Ca PRI using the original sets of FBRs and a small (500 mL/day) portion of a calcium-fortified water with 100 or 400 mg/L. Larger portions (1000 mL) of a calcium water with 100 mg/L were only needed in the Western Highlands of Guatemala. Combining fortified flour with FBRs also meant the Ca PRI target was met in calcium-minimized diets for young adolescent girls in Bangladesh. Furthermore, the addition of fortified flour or water meant that FBR sets could be reduced from 3–4 to 1–2 FBRs, with 500 mL/day portion of high-calcium tap water in Uganda, if high-calcium flour or 1000 mL/day of 400 mg/L water was used in Bangladesh, and if 1000 mL/day of 400–500 mg/L bottled water was used in Guatemala.[14] A similar exploratory Optifood analysis in Kenya found that combining FBRs based on local foods with zinc-fortified water could improve nutrient adequacy among pre-school-aged children.[15] The ionic nature of calcium in water makes it highly bioavailable, similar to or higher than in dairy products.[9,22,58] Additionally, water can be consumed on its own, independently of meals and associated phytate intake, which can limit calcium absorption.[9]

This analysis did not consider food prices, consumer-facing price implications of fortifying water or flour with calcium, or household purchasing power when optimizing diets and testing FBRs. However, it has been estimated in previous analyses that nutritious diets would be inaccessible for many households in Guatemala, Bangladesh, and Uganda.[59–61] Interventions that reduce the number of FBRs required to meet nutrient intake targets, such as fortifying products that are already consumed, could increase the feasibility of promoting such dietary change in terms of availability, affordability, and acceptability of consuming the FBR foods in recommended quantities. This, however, would require fortified water or flour to be available and accessible to poor households, such as through local production and market interventions and subsidies, vouchers, or in-kind provisions.

Flour fortification is widely used and many countries have mandatory legislation to fortify flour with at least one micronutrient, which facilitates the incorporation of calcium.[62] While wheat flour fortification is mandatory in Uganda and Guatemala, the specifications do not include calcium.[13] Conversely, the Bangladesh fortified wheat flour specifications do include calcium, but the standards are voluntary and only recommend 5.3 mg of calcium per 100 g of flour.[13] The feasibility of flour fortification at the higher levels of 400 mg of calcium per 100 g, as modeled in this analysis, would require further feasibility testing. In addition to the development and procurement of micronutrient premix, the inclusion of calcium in flour fortification programs or standards would require monitoring and enforcement of compliance to ensure that fortified foods are reaching the most vulnerable.[63] Analysis with existing tools, such as those developed under MINIMOD, could be used to model the potential cost implications of adding calcium to wheat flour premix or increasing its calcium content.[64] However, as wheat flour is not widely consumed in all countries,[8,10] prior to recommending this flour fortification as a strategy, analysis using the HECS data from this study or primary data should confirm whether those consuming wheat flour in countries such as Bangladesh are the same population groups with low calcium intakes who could benefit from a fortification strategy, or if a different fortification vehicle should be selected. Depending on the context, additional analysis should also test the potential contribution of fortifying other, more broadly consumed and accessible foods, such as maize or rice, with calcium, or increasing the calcium content of common staple foods using biofortification.[22,65,66]

Water is universally consumed, and as such, the calcium content of water could impact the diets of most populations.[22] However, water intake is rarely captured in dietary surveys; for this reason, this analysis tested different daily water portions. Nutritional assessments should incorporate measures of individual water intake, drinking water sources, and calcium content of local water sources to improve calcium dietary estimations and inform strategies for addressing low intake.[67] If the calcium content of local water sources is low, the development of strategies to improve the calcium content of water could be explored.[11] Improving the calcium content of tap water should take into account regulations of water hardness and the extent to which tap water is used for purposes other than human consumption.[20] Improving the calcium content of nontap drinking water, such as bottled water, would allow higher calcium concentration and, consequently, greater health benefits.[21,68] Commercial brands of bottled water with high calcium concentrations exist in many markets globally; however, the populations who are most vulnerable to low calcium intake are unlikely to have economic and physical access to bottled water. According to the HCES data used for this study, tube wells are the main water source for 95% of households in rural Bangladesh, and bottled water was the main water source for less than 1%.[31] In Guatemala, an average of 10% of households in rural areas purchase bottled water, compared to 40% of urban households.[46] In Uganda, bottled water is accessed by less than 5% of households.[69] Strategies to improve access to clean, safe water such as water tanker trucks or programs distributing drinking water in containers have synergies with strategies to provide access to high-calcium water for populations vulnerable to low intake and there is potential for collaboration.[11,67,70–72] This is especially relevant for contexts in which tap water is not currently safe for consumption; consuming microbiological clean drinking water could reduce the incidence of diarrhea and other infections.[14] However, if such programs were to be combined to provide clean water that was also high in micronutrients, it would be important to monitor compliance of micronutrient fortification, as well as water safety. Alternatively, treated tap water distributed via centralized systems would be easier to regulate and monitor as it would be possible to measure calcium levels at the source. For commercial bottled water, industry checks would apply. The program costs and cost-effectiveness of implementing flour or water calcium fortification strategies should be explored within the context of each study country; in certain contexts, adding calcium or improving its concentration in fortification premix is likely to be more cost-effective than introducing a new intervention.[73]

To achieve the modeled contributions reported here, further studies should explore the feasibility and acceptability of introducing and promoting calcium-fortified water and wheat flour for the most nutritionally vulnerable population groups. More research is also required to explore the programmatic implications, including cost, of producing and distributing high-calcium water to populations at risk of low calcium intakes. Lastly, evidence from prolonged calcium supplementation shows no adverse effect on iron status; however, the potential interaction of calcium with other fortificants should be explored.[2,74]

The Optifood tool can model the potential contribution of nutrient-dense products, such as calcium-fortified flour or water, to local diets in the context of current food systems and dietary patterns.[28] The LPA rapidly generates diets while simultaneously considering available and proposed foods, their nutrient composition, how these foods are eaten by the target group, and RNIs. This allows fortified products to be explored as part of whole diets and identify commonly consumed foods that could also be promoted to improve micronutrient intake.[50] However, the modeling in Optifood is a simulation based on overall observed dietary patterns and is unable to explore the percentage of the population at risk of inadequate intake or exceeding the UL of consumption. Other tools, such as the Intake Modeling, Assessment and Planning Program, would be able to provide more refined estimates of risk but would have distinct data requirements.[75] Also, the Optifood results are dependent on the accuracy of data inputs, specifically the list of consumed foods, upper and lower limits of consumption, and portion sizes, as well as food composition data.[48] While modeled foods were reportedly consumed at the household level in the input data, they may not actually be available or accessible in the recommended quantities to all target group members or at all times.[35] Furthermore, the nutrient composition of foods can vary within and across countries; as such, both the matching of foods to food composition data and inaccuracies in these data could have affected results.[48]

This analysis was based on secondary household consumption data collected between 2013 and 2015. While more recent HECS rounds have been conducted in Bangladesh and Uganda, these datasets were not available at the time data were originally accessed and processed for this study. As only small shifts in the consumption of nutrient-dense food items (such as animal source foods) were found in an analysis comparing Malawian data from one HCES reporting period to the next,[76] and as the Optifood analysis is based on a range of consumption patterns across the population, rather than an average, we do not expect that newer data would result in changes to the final outputs. Lastly, this study simulated the potential of optimized local diets to achieve calcium intake targets (100% of Ca PRI in optimized diets or 65% of Ca PRI in minimized diets), but it should be noted that population-level nutrient intakes are usually evaluated using average nutrient requirements that represent a lower fraction of the calcium PRI.

CONCLUSIONS

This simulation study shows that combining calcium fortification of flour or drinking water with FBRs to increase calcium intake within the context of local food systems could help modeled diets meet calcium intake targets. These strategies combined are unlikely to pose any risk of exceeding the calcium UL in infants, children, and adolescents. More updated nutritional data, including characteristics of populations consuming flour and actual drinking water intake and calcium content of drinking water, would be required to design strategies to improve calcium intake.

AUTHOR CONTRIBUTIONS

The authors' responsibilities were as follows: F.K., M.W.B., and E.L.F. conceptualized the project; F.K., E.F., and G.C. conceptualized the analyses. F.K. and E.L.F. did the analyses. F.K., E.L.F., and G.C. wrote the first draft of the manuscript. All authors edited the manuscript and approved the final version.

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COMPETING INTERESTS

The authors declare no competing interests.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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