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Review

Current calcium fortification experiences: a review

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Low dietary calcium is very common in many populations, contributing to nutritional rickets/osteomalacia in children/adults and increasing the risk of several health problems. Calcium is a nutrient of concern as the recommended nutrient requirements are difficult to meet in the absence of dairy products. The provision of culturally acceptable calcium-fortified foods may improve calcium intake when it is a feasible and cost-effective strategy in a particular setting. This landscape review was conducted in 2019 and describes current calcium fortification efforts and lessons learned from these experiences. Worldwide, the United Kingdom is the only country where calcium fortification of wheat flour is mandatory. It is estimated that this fortified staple ingredient contributes to 13–14% of calcium intake of the British population. Other items voluntary fortified with calcium include maize flour, rice, and water. Current calcium fortification programs may lack qualified personnel/training, clear guidelines on implementation, regulation, monitoring/evaluation, and functional indicators. Also, the cost of calcium premix is high and the target groups may be hard to reach. There is a lack of rigorous evaluation, particularly in settings with multiple micronutrient programs implemented simultaneously, with low quality of the evidence. Further research is needed to assess the impact of calcium fortification programs.

Keywords: calcium; fortification; mandatory; voluntary; program; guidelines

Introduction

Dietary calcium intake in low-income settings is typically poor.[1,2] Although low calcium intake has been identified in many countries for several years, it has not been prioritized by most countries. This may be because low calcium intake is not viewed as being a life-threatening condition in the overall population as compared with other key nutrients but rather associated with more chronic conditions. However, low calcium intake is associated with several adverse health conditions, including preeclampsia and hypertension, which are life-threatening.[3,4] Calcium supplementation in pregnant women has been shown to reduce the incidence and severity of complications of preeclampsia,[5] which is a life-threatening condition for both mother and infant. Based on trials of calcium supplementation during pregnancy for preventing preeclampsia,[1,6] the World Health Organization (WHO) recommends calcium supplementation in pregnancy, particularly in settings of low calcium intake.[7] Besides, a new calcium supplementation trial confirms that improving calcium intake before pregnancy has further benefits, which opens the target population to all women.[6]

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There are major acceptability and feasibility concerns with the WHO recommendation of calcium supplements, such as pill burden, high cost, low adherence, complex supply chain, side effects, and nonuse of health services. These are major barriers to scale up the adoption of calcium supplementation. Therefore, the discussion has moved in recent years to staple food fortification as an effective means to help achieve adequate levels of calcium intake which, in principle, would have benefits beyond pregnancy and beyond women. In addition, fortification would increase the reach to remote populations or populations that lack contact with the health system.

This landscape review represents a comprehensive assessment of the current calcium fortification efforts and lessons learned from these experiences up to 2019. The information was identified through internet search engines and databases, such as Google, PubMed, Agricola, and CINAHL. We also reviewed reports from the WHO, Food Agriculture Organization, Institute of Medicine, Global Alliance for Improved Nutrition (GAIN), Micronutrient Initiative, Global Fortification Data Exchange (GFDx), Food Fortification Initiative (FFI), Global Dietary Database, Iodine Global Network (IGN), and European Food Safety Authority, among others.

Health benefits and risks of calcium intake

Calcium is one of the main bone-forming minerals and 99% of the body's calcium resides in the skeleton. This reservoir of calcium not only serves to provide strength and support for the skeleton but also to meet the demands for intra- and extracellular calcium. Beyond bone health, calcium has several vital functions, such as blood clotting, cell adhesion, muscle contraction, activation of enzymatic reactions, hormone and neurotransmitter release, glycogen metabolism, and cell proliferation and differentiation.

Very low calcium intake results in nutritional rickets in children and osteomalacia in adults and increases the risk of osteoporosis, while an adequate calcium intake leads to positive bone mass, prevention of bone loss, and prevention of fractures in different age groups.[3,4] Adequate calcium intake, particularly if it comes from foods and beverages, may reduce the risk of periodontal disease, hypertensive disorders, colorectal adenomas, nephrolithiasis (kidney stones), coronary artery disease, insulin resistance, and obesity.[4] On the other hand, some population studies have shown that the use of calcium supplements leading to excessive calcium intake (>2500 mg/per day) may increase the risk of hypercalcemia, renal insufficiency, milk-alkali syndrome, and even kidney stones.[4] Some studies have also suggested a greater risk of cardiovascular events[8–12] and prostate cancer in certain populations.[13,14] Recent large meta-analyses have questioned this evidence,[15,16] and thus it may be insufficient to inform nutritional requirements.[2,17] In addition, the trials using 1.5–2 g in prepregnant and pregnant women did not show adverse events.[1,6]

Calcium fortification has shown to improve overall calcium intake in the population, as shown in the United Kingdom (UK), in which mandatory fortification of wheat flour with calcium (except wholemeal and some self-raising varieties) has been in effect since 1943.[18] This is the only mandatory program of calcium fortification worldwide and contributes to about 14% of total calcium intake in the total population[19] and 13% in adolescents.[20] An impact assessment conducted by the National Health Service in the UK found that if calcium were removed from wheat flour, about 21% of girls, 12% of boys, and 6–9% of women aged 19–64 years would have intakes below the lower reference nutrient intake.[21] It would also affect small children aged 1–3 years. The report also states that this hypothetical increased risk of calcium deficiency could affect bone health and estimated that the elimination of the mandatory calcium fortification could increase fractures in the hip, spine, and forearm by 2% per year.

In the United States, fortification of wheat flour with calcium has been estimated to reduce the proportion of individuals not meeting the estimated average requirement (EAR), from 54% (when only foods from naturally rich sources were taken into account) to 38% (when calcium-fortified foods and supplements were taken into account).[22] Therefore, calcium fortification of wheat flour, if feasible and acceptable, could be a way of improving calcium intake at the population level. Considering that food fortification would probably not increase calcium intake to levels higher than calcium supplementation in most individuals if planned properly, it would seem safe to fortify foods or beverages of common consumption with calcium, particularly among populations with low calcium intake. However, the planning of any food fortification would require simulation studies to assess the impact of the strategy to confirm that calcium intake upper limits are not exceeded. Voluntary fortification of commonly consumed foods and beverages could be considered to maintain the principles of food fortification of not changing usual diets or encouraging the excessive consumption of one product on the sole basis of their calcium nutritional contents.

Calcium intake recommendations and global estimates on calcium intake

Calcium intake recommendations

Compared with other nutrients, calcium is needed in relatively large amounts. However, there is no uniform criterion for setting calcium recommendations worldwide. Different methodologies, nomenclatures, and age groups have been used. In addition, calcium needs may vary depending on the population intakes of phytate, oxalate, salt, caffeine, and protein, which all have been shown to reduce calcium retention. In particular, intake of oxalate and phytate impairs calcium absorption by forming insoluble complexes with calcium. A diet high in salt and phosphate promotes calcium loss in urine. In addition, vitamin D intake and/or sun exposure may also alter calcium needs, as vitamin D is needed for calcium absorption and retention. All this could also contribute to the development and progression of rickets.[23]

The WHO/FAO recommendations for calcium vary greatly depending on the age and gender and life stages (pregnancy and lactation) (Table 1).[24] It ranges from 300–400 mg/day of calcium in infants to 1300 mg/day in children 9–18 years and in older adults. However, the WHO recognizes special situations in which calcium supplementation or higher levels may be needed. During pregnancy, among populations with low calcium intake, calcium supplementation is recommended as part of the antenatal care for the prevention of preeclampsia, particularly among those at higher risk of developing hypertension.[7] The recommended dose is 1.5–2.0 g/day of elemental calcium, which should be divided into three doses (preferably taken at mealtimes). Supplementation is recommended from 20 weeks gestation until the end of pregnancy. The reason for this high dose and timing is that this was the dose and timing used in most trials, and a lack of adequate trials testing a lower dose. Also, breastfed, very low birth weight infants should be supplemented with calcium at a rate of 120–140 mg/kg per day during the first months of life.[25]

Table 1. WHO/FAO recommended calcium allowances based on Western European, American, and Canadian data[24]

Group	Calcium intake mg/day
Infants and children	
0–6 months	
• Human milk	300
• Cow milk	400
7–12 months	400
1–3 years	500
4–6 years	600
7–9 years	700
Adolescents, 10–18 years	1300[a]
Adults	
Females	
• 19 years to menopause	1000
• Postmenopause	1300
Males	
• 19–65 years	1000
• 65 +	1300
Pregnancy (last trimester)	1200
Lactation	1000

[a]Particularly during the growth spurt.

In the United States[4] and in some countries in Europe,[26] country-specific recommendations are higher compared with those from WHO. Also, these recommendations are country-specific and may not necessarily apply to other countries with different dietary patterns, lifestyles, and environments.

Prevalence of low calcium intake

Low calcium intake is common worldwide. This is mainly related to the low dietary diversity seen in many countries, where often most of the energy is obtained from wheat, maize, or rice, cereals that have very low calcium content. Because of the lack of general awareness of the status of calcium intake, we performed a thorough analysis of calcium intake worldwide for this landscape review. We specifically searched for available national nutritional surveys from 2000 to 2019. Table 2 shows the data found by gender and age groups. Calcium intake differs widely between groups and populations. In children, this varies from as low as

Table 2. Global calcium intake (mg/day) by gender and age groups in available national nutritional surveys from 2000 to 2019[a]

Country	Survey years	Infants and children	Adolescents	Adults	Elderly	Sample size	Calcium intake assessment
Argentina[73]	ENNyS 2017	702 (6–23 months); 700 (2–5 years)		367 (10–49 years)		42,722	24-h recalls
Australia[74]	Australian Health Survey 2011–2012			805 (19 years^{+})		9338	24-h recalls
Austria[75]	Austrian Nutrition Report 2010–2012			F: 860; M: 891 (18–64 years)	F: 632; M: 692 (65–80 years)	1002	3-day-diary/ 24-h recalls
Bangladesh[76]	BIHS 2011–2012			272		22,173	24-h recalls
Belgium[77]	BNCFS 2014			F: 721; M: 819 (18–64 years)		3146	24-h recalls
Bolivia[78]	MECOVI Household Surveys 1999–2002			458		19,483 households	FFQ
Brazil[79–81]	National Dietary Survey, 2008–2009 Household Budget Survey	F: 469; M: 482 (10–13 years)	F: 507; M: 369 (14–18 years)	F: 477; M: 550 (20–59 years); F: 487 (51–59 years)	F: 477; M: 500 (60 years^{+})	34,032	Food records
Cambodia[82]	SEANUTS 2011	Urban F: 358; M: 361 (6–9 years) F: 390; M: 428 (10–12 years) Rural F: 311; M: 330 (6–9 years) F: 411; M: 342 (10–12 years)	Urban F: 632; M: 463 Rural F: 632; M: 676 (13–17 years)			2020	24-h recalls
Canada[83]	CCHS (cycle 2.2) 2004	1044 (1–3 years); 1088 (4–8 years) F: 950; M: 1151 (9–13 years)	F: 884; M: 1227 (14–18 years)	F: 820; M: 1028 (19–30 years); F: 786; M: 888 (31–50 years); F: 699; M: 774 (51–70 years)	F: 664; M: 708 (≥71 years)	35,107	24-h recalls
China[84]	CHNS 2019		F: 355 (10–17 years); M: 426 (12–19 years)			2019	24-h recalls
Denmark[85]	Danish National Survey of Dietary Habits and PA 2000–2002			F: 990; M: 1055 (19–64 years); F: 1038; M: 1188 (4–75 years)	F: 900; M: 874 (>64 years)	3098	7 days dietary record
Estonia[85]	National Dietary Survey			F: 658; M: 770 (18–64 years)	F: 584; M: 678 (65–74 years)	4906	24-h recalls and FFQ (>2)
Finland[87]	FINDIET 2012			1242 (25–64 years)	1056 (65–74 years)	795	48-h recalls
France[88]	INCA2, 2006–2007			F: 850; M: 984 (18–79 years)		4709	7-day diary
Germany[89]	German National Nutrition Survey II 2005–2007			F: 1171; M: 1047 (19–64 years)	F: 918; M: 970 (>6 years)	13,959	Diet history
Hungary[90]	Hungarian dietary survey 2007			F: 669; M: 735 (19–60 years)	F: 636; M: 635 (60 years^{+})	3077	3-day diary, FFQ
Iceland[91]	Diet of Icelanders-national dietary survey 2010–11			F: 885; M: 1131 (18–60 years)	F: 694; M: 847 (61–80 years)	1312	24-h recalls and FFQ
Indonesia[92]	SEANUTS 2011	Urban F: 486; M: 526 (0.5–2 years); F: 408; M: 450 (2–5 years) F: 234; M: 266 (5–12 years) Rural F: 314; M: 345 (0.5–2 years); F: 260; M: 250 (2–5 years) F: 180; M: 195 (5–12 years)				7211	24-h recalls

Continued

Table 2. ***Continued***

Country	Survey years	Infants and children	Adolescents	Adults	Elderly	Sample size	Calcium intake assessment
Ireland[93]	National Adult Nutrition Survey 2010			1080 (18–90 years)		1499	Food record
Italy[94]	INRAN-SCAI 2005–2006: part 1	664 (0–3 years); 749 (3–10 years)	F: 770; M: 892 (10–18 years)	F: 730; M: 779 (18–65 years)	F: 754; M: 825 (>65 years)	2831	24-h recalls
Japan[95]	NHNS 2017	F: 369; M: 417 (1–6 years); F: 646; M: 698 (7–14 years)	F: 462; M: 528 (15–19 years)	F: 467; M: 471 (20–69 years)	F: 560; M: 583 (70 years+)	6962	Diet history
Kenya[96]	Kenya National Micronutrient Survey 2011	390 (12–59 months)		F: 581 (15–49 years)		660	24-h recalls
Malawi[97]	IHS3, 2010–2011			Urban: 1021; Rural: 649 (15–49 years)		12,271	7-day recall
Malaysia[98,99]	MANS, 2003; SEANUTS 2011	Urban F: 578; M: 532 (0.5–0.9 months); F: 682; M: 706 (1–3.9 years) F: 673; M: 673 (4–6.9 years); F: 775; M: 777; (7–12 years) Rural F: 578; M: 755 (0.5–0.9 months); F: 734; M: 694 (1–3.9 years); F: 672; M: 707 (4–6.9 years); F: 696; M: 741 (7–12 years)	F: 326; M: 391 (18–19 years);	Urban M: 419; F: 378 Rural M: 418; F: 371 By age groups F: 387; M: 425 (20–29 years); F: 386; M: 430 (30–39 years); F: 367; M: 402 (40–49 years); F: 379; M: 430 (50–59 years);		3542 (6 months–12 years); 6886 (18–59 years)	24-h recalls
Mexico[100]	ENSANUT 2012	828 (1–4 years); F: 816; M: 866 (5–11 years)	F: 796; M: 921 (12–19 years)	F: 723; M: 819 (>20 years)		10,096	24-h recalls
Pakistan[101]	National Nutrition Survey 2011	489 (0–23 months)		F: 456 (20–34 years)		187,095	24-h recalls
Philippines[102]	National Nutrition Survey 2013	522 (6–12 months); 479 (12–24 months); 421 (24–36 months); 286 (36–60 months)				4218	24-h recalls
Portugal[103]	IAN-AF 2015–2016			F: 731; M: 830 (18–64 years)	F: 724; M: 764 (65–84 years)	4221	24-h recalls, FFQ, 2-day food diary
Spain[86,89]	ENCAT 2002–2003			F: 778; M: 830 (19–64 years); F: 835; M: 884 (18–64 years)	F: 900; M: 757 (>64 years)	1923	24-h recalls
Sweden[104]	Riksmaten 2010–2011			F: 820; M: 967 (18–64 years)	F: 826; M: 885 (65–80 years)	1797	4-day diary
Thailand[105]	SEANUTS 2011	Urban: 593 (0.5–3 years); 602 (3–6 years); 602 (6–13 years) Rural: 541 (0.5–3 years); 527 (3–6 years); 352 (6–13 years)				3119	24-h recalls
Turkey[106]	TNHS 2010			F: 592; M: 968 (18–64 years)	F: 521; M: 635 (65–75 years^{+})	14,248	24-h recalls and FFQ
United Kingdom[107]	NDNS RP 2008–2012			F: 728; M: 888 (19–64 years)	F: 796; M: 852 (65 years^{+})	6828	4-day diary
United States[108]	NHANES 2001–10			927 (19 years^{+})		22,823	24-h recalls

^{a}Search of National surveys was performed by a structured search of publications in Pudmed/Medline and CINAHL, the Vitamin and Mineral Nutrition Information System of the WHO, the Global Health Data Exchange from the University of Washington, the Global Dietary Database from Tufts University, and also a general internet search using terms, such as "national nutrition survey" from 2000 to 2019.

FFQ, food frequency questionnaire; M, males; F, females.

234 mg/day in girls aged 5–12 years from Indonesia to as high as 1151 mg/day in boys aged 9–13 years from Canada. In adolescents, this varies from as low as 326 mg/day in girls aged 18–19 years from Malaysia to as high as 1227 mg/day in boys 14–18 years from Canada. In adults, this varies from as low as 272 mg/day in Bangladesh to as high as 1242 mg/day in men from Finland. In general, the highest intakes (~950 mg/day or more) are seen in Finland, Denmark, Ireland, and Germany, and the lowest intakes (~500 mg/day or less) are seen in Argentina, Brazil, Bolivia, Indonesia, Japan, Kenya, Malaysia, Pakistan, and the Philippines, which are mostly low- and middle-income countries.

Several efforts have been conducted to map calcium intake worldwide, such as the International Osteoporosis Foundation Calcium Steering Committee.[27] These data show that most countries with very low calcium intake are clustered in the Asia-Pacific region, but also in South America and in a few countries in Africa (although most countries do not have data). Conversely, those with calcium intake above 1000 mg/day were in Northern Europe.[27] Asian countries have traditionally low intakes of dairy products; for example, in China, the main calcium food sources are vegetables (30.2%), legumes (16.7%), and cereals (14.6%).[28] However, in northern Europe, the main food sources of calcium are dairy products but also dark green vegetables, legumes, nuts, canned fish with their bones, calcium-fortified foods (i.e., breakfast cereals and breads), and hard water.[26] It is interesting to note that Mexico and Jamaica have the highest calcium intake in the Americas, after the United States. In particular, in Jamaica, condensed canned milk is highly consumed, as well as cheese and Chinese cabbage (which contains 79 mg of calcium per serving and it is well absorbed) and milk with tea.[29] Other main calcium food sources in Jamaica include cereals and vegetables (particularly dark green leafy and yellow vegetables, each contributing to 17% of total calcium intake, fruits (11%), dairy products (9%), and seafood (6%)).[30] In Mexico, there is a very high intake of corn tortillas,[31,32] which are processed by soaking boiled corn overnight in a lime solution that contains calcium hydroxide, a process entitled nixtamalization.[33] Calcium absorption from the traditional home process is higher than the commercially available tortillas, thereby becoming an important calcium source in these countries.

Among pregnant women, a review by Cormick *et al.*[34] found very different levels of calcium intake by country income level. Among high-income countries (50 studies), such as Australia, Belgium, Canada, Greece, Israel, Japan, Netherlands, New Zealand, Norway, Poland, Portugal, Saudi Arabia, South Korea, Spain, Taiwan, the UK, and the United States, the mean calcium intake was 948 mg/day (95% CI: 872–1024 mg/day). However, among low- and middle-income countries (41 studies), such as Argentina, Brazil, China, Colombia, Egypt, Ethiopia, India, Iran, Jordan, Kenya, Malaysia, Morocco, Nepal, Pakistan, South Africa, Thailand, and Turkey, mean calcium intake was 648 mg/day (95% CI: 569–727 mg/day). When grouped by regions, mean calcium intake in Latin America (10 studies) was 622 mg/day (95% CI: 400–843 mg/day), in Africa (5 studies) was 566 mg/day (95% CI: 408–724 mg/day), in Asia Pacific (32 studies) was 653 mg/day (95% CI: 584–722 mg/day), in Western Europe and others group (43 studies) was 989 mg/day (95% CI: 921–1056 mg/day), and Eastern Europe (1 study) was 1235 mg/day (95% CI: 1102–1368 mg/day). This report also found that when considering a threshold of 800 mg/day of calcium (the EAR established by the Institute of Medicine), 28% of high-income countries reported a low calcium intake, while this was 88% among low- and middle-income countries.

Micronutrient fortification programs worldwide

Before describing calcium food fortification programs, we deemed it important to provide an overall description of current national micronutrient food fortification programs. Based on the WHO Global nutrition policy review from 2018, 68% of a total of 155 countries surveyed have a national food fortification program.[35] The most common fortification program is salt fortification, followed by wheat flour and oil. Maize flour or cornmeal is also a popular staple to fortify, particularly in Africa and the Americas. Sugar is fortified more often in the Americas, while rice is fortified most often in Asia. Condiments are less frequently fortified. Some countries fortify more than one staple food: countries fortifying maize flour or cornmeal also have rice and wheat flour fortification programs in place. The most common nutrients added to these foods are iodine, iron, folic acid, thiamin, niacin, riboflavin, and vitamin A.

Of a total of 195 countries (193 countries that are member states of the United Nations and two countries that are nonmember observer states), 86 countries are fortifying wheat flour with at least two or more of these nutrients: folate, iron, niacin, riboflavin, thiamin, vitamin A, vitamin B12, vitamin B6, and zinc.[35,36] Also, 19 countries are fortifying maize flour with at least two of these nutrients: folate, iron, niacin, riboflavin, thiamin, vitamin A, vitamin B12, vitamin B6, and zinc. Other foods that are being fortified with one or more micronutrients include condiments (i.e., soy and fish sauces and bouillon cubes), milk, and refined sugar, among others.

Such food fortification programs have shown to have an impact on various outcomes.[37] For example, in children and women, these programs have shown a significant positive effect on hemoglobin and serum ferritin concentrations, and in the reduction of anemia prevalence. Also, multiple micronutrient fortification has been shown to be beneficial in reducing anemia and iron deficiency in children.[38] Fortified blended foods, which are blends of partially precooked and milled cereals, soya, beans, pulses fortified with micronutrients, including calcium,[39] and that are used in World Food Programme (WFP) Supplementary Feeding and Mother and Child Health programs to prevent and address nutritional deficiencies,[40] have also shown promising results. For example, in infants and young in Haiti, corn-soy blends significantly contributed to improving the quality of the diet in these children.[41] The acceptance of the product has been good in children and women from different settings.[42–44] Evaluation of national fortification programs from Morocco, Uzbekistan, and Vietnam of wheat flour and fish sauce showed that all had key achievements.[45]

Calcium fortification programs worldwide

Description of national calcium fortification programs and/or regulations

Calcium is used less frequently. When reviewing the national food fortification efforts that include calcium, we found that calcium may be added to certain staple foods, such as in wheat flour, maize flour or cornmeal, rice, and milk.[35,36] However, as mentioned previously, the UK is the only country with a mandated calcium fortification program at the national level for wheat flour.[46] However, a few countries have official regulations and/or food standards that provide guidance for voluntary fortification of foods with calcium, which can be implemented by the different food producers.[46] We conducted a thorough review of the literature and institutional webpages, such as Global Fortification Data Exchange and other sources, to gather data on the regulations for calcium fortification of staple foods in different countries.

Wheat flour. Wheat flour (except wholemeal and some self-raising varieties) in the UK is mandated to be fortified with calcium.[18] Other countries have regulations and/or standards for voluntary calcium fortification; these are Zambia (Africa); Antigua and Barbuda, Bahamas, Barbados, Belize, Colombia, Dominica, Grenada, Guyana, Jamaica, Saint Kitts & Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, and the United States of America (Americas); Bangladesh, China, Jordan, Qatar, and United Arab Emirates (Asia).[36,47,48] At the regional level, only the Caribbean Community (CARICOM) has set standards for calcium fortification of wheat flour.

Other staple foods. There are regulations at the national level for voluntary fortification of maize flour with calcium only in Zambia and the United States.[36] Canada also allows the addition of calcium to cornmeal. Belize and the United States also have regulations for voluntary fortification of rice with calcium.[36]

Water. Water is naturally a potential source of calcium and may be an efficient way of providing and improving calcium intake in countries with very low calcium intake. A thorough review of the literature demonstrated that there is a large variation in the calcium content in water, as shown in Table 3. This variation may be explained by the levels of nutrients in soils, by the water source, and also by different treatments applied to water.[49] For example, in some areas with high levels of water hardness (usually expressed as mg/L of calcium carbonate), water is softened to reduce levels of minerals. Bottled waters can be mineralized or demineralized to increase or reduce minerals. The final calcium content of drinking water depends on the distribution system and its regulations, but also taste and acceptance. The taste

Table 3. Calcium content in different sources and types of water[50,52,109–112]

Water source	Calcium (mg/L) (mean ± standard deviation)
North American tap water	
Surface water sources ($n = 36$)	34 ± 21
Ground water sources ($n = 8$)	52 ± 24
U.S. tap water ($n = 33$)	51 ± 29
Canada tap water ($n = 6$)	49 ± 53
North American bottled waters	
Spring water ($n = 28$)	18 ± 22
Mineral water ($n = 9$)	100 ± 125
European bottled waters	
Low mineralization waters ($n = 40$)	60 ± 40
Moderate mineralization waters ($n = 26$)	262 ± 139
High mineralization waters ($n = 7$)	60 ± 59
Portugal bottled and mineral waters ($n = 1$)	97 ± 9
United Kingdom bottled and mineral waters ($n = 1$)	24 ± 2
European public waters	
Spain ($n = 108$)	39 ± 32
Middle East	
Algeria public water ($n = 40$)	194 ± 31
Worldwide	
Surface water sources ($n = 36$)	34 ± 21
Groundwater sources ($n = 8$)	52 ± 24
Spring water ($n = 28$)	18 ± 22
Mineral water ($n = 29$)	100 ± 125
Low-mineral water ($n = 40$)	60 ± 40
Medium-mineral water ($n = 26$)	262 ± 139
High-mineral water ($n = 7$)	60 ± 59
Water source	Calcium (mg/L) (range (minimum–maximum))
North American bottled waters	
U.S. bottled and mineral waters ($n = 10$)	0–58
European bottled waters	
France bottled and mineral waters ($n = 14$)	10–528
Belgium bottled and mineral waters ($n = 4$)	10–112
Italy bottled and mineral waters ($n = 5$)	20–414
Spain bottled and mineral waters ($n = 97$)	40 (1–610)
Worldwide	
Distilled water ($n = 9$)	0
Mineral water ($n = 4$)	12 (0–21)
Imported mineral water ($n = 12$)	12–199
Water source	Calcium (mg/L) (mean)
Seawater	
Typical	400
Eastern Mediterranean	423
Arabian Gulf at Kuwait	500
Red Sea at Jeddah	225

threshold for the calcium ion depends among other things on the chemical composition of water, and it is suggested to be in the range of 100–300 mg/L; however, consumers may tolerate levels higher than 500 milligrams per liter.[49]

Depending on the water intake and calcium concentration, water can be an important contributor to the diet. A study in Spain in 2014 simulated the contribution of water to total calcium intake, assuming water consumption is at the recommended levels.[50] Among municipalities with public water containing 50–100 mg/L of calcium, this would provide 5–13% of the recommendation for children, about 14% for adolescents, 6–18% for adults, and about 21% for lactating mothers. Among municipalities with calcium in water at 100–150 mg/L, this would provide about 10–31% of the recommended levels. Another study in France assessed the contribution of mineral water with different calcium levels.[51] Individuals who were regular drinkers of high calcium mineral water (486 mg/L) had a mean calcium intake from water of 298 ± 170 mg/day in women and 308 ± 171 mg/day in men, while individuals with intermediate calcium mineral water intake (202 mg/L) had a mean calcium intake from water of 117 ± 76 mg/day in women and 120 ± 74 mg/day in men. Among those drinking waters with low calcium content (9.9–67.6 mg/L), the contribution of calcium from water was negligible and this was significantly lower than the high calcium mineral water group. It is important to note that contribution of calcium from foods did not differ between the groups. Therefore, calcium-rich mineral water may contribute to about one-fourth of the total daily calcium intake, depending on the age group. In the United States, a study also estimated that if about six cups of water are consumed per day, calcium contribution from water would be about 5.2% of the total daily calcium intake in the United States and 5.0% in Canada.[52]

The bioavailability of calcium from water has been extensively studied since 1990, with about 10 studies comparing it with dairy products.[53] Six of these studies evaluated calcium absorption using the tracer technique with isotopes, while the others used indirect measurements, such as serum parathyroid levels, a hormone that regulates calcium metabolism, or calcium in serum or urine. All studies agreed that calcium in water is highly bioavailable, similar to or higher than dairy products.

Evaluation and impact of calcium food fortification programs

Data from the UK show that mandatory fortification of wheat flour with calcium has been estimated to contribute to about 14% of total calcium intake in the country[18] and 13% of total calcium intake in adolescents.[20] Without this contribution, about 10–12% of adolescents would have intakes below the lower reference nutrient intake. In Denmark, mandatory fortification of flours with calcium (200 mg/100 g wheat flour and 400 mg/100 g rye flour) was in effect from 1954 until 1987. This program started based on the assumption that calcium intake was insufficient in certain subgroups in this country. However, it stopped in 1987 after the results from the nationwide food survey conducted in 1985 showed that calcium intake was adequate.[54]

However, a study evaluating this change found that calcium fortification of wheat and rye flours appeared to provide 30% of the total calcium intake.[55] Also, the percentage of adults not meeting the daily requirement increased from 6% to 22% when evaluated in 1993/1994 compared with intake in 1987/1988, when the fortification was still in effect. The authors also calculated that if all flour consumed in 1987/1988 was calcium-fortified, then the percentage of individuals consuming calcium under the recommendation would only be 6% in men and 7% in women. However, without the calcium fortification program, this would increase to 21% in men and 24% in women, as those individuals not complying with recommendations have generally less consumption of dairy products. Although it is not clear what are the health impacts of stopping calcium fortification in Denmark in the long term, an epidemiological study did show an increase in hip fracture among the cohort born in 1933–1940, who were about 50–53 years old in 1987–1990 (when calcium fortification stopped).[56] The true impact may be seen among those who were adolescents in 1987, when most of the peak bone mass is acquired and, therefore, the most important age for preventing osteoporotic fractures later in life. Therefore, the negative effects on bone from the withdrawal of the mandatory calcium fortification may not be apparent before the 2030s. In the United States, although the addition of calcium to flours is voluntary, it is an important contributor of calcium at the population level as shown in a study using NHANES data from 2003 to 2006, in which it helped reduce the proportion of individuals not meeting the EAR from 54% to 38%.[22]

In terms of evaluation, there are a few studies that have evaluated the impact of different calcium food fortification programs on markers of calcium metabolism in the blood, such as parathyroid hormone, serum calcium, and serum vitamin D. In two studies including 317 children, it was reported that fortification with only calcium resulted in a standard mean difference of −0.28 (95% CI: −0.50 to −0.06) in parathyroid hormone levels and one study in 231 children found a standard mean difference of −0.30 (95% CI: −0.56 to −0.04) in serum calcium levels.[57] In women, three studies with only calcium fortification found a standard mean difference of 0.69 (95% CI: 0.38–1.00) in serum vitamin D levels. The quality of the evidence was low.[58]

Another systematic review and meta-analysis evaluated the impact of micronutrient-fortified dairy products and cereal foods on the health of children and adolescents.[59] A total of 24 trials from low- and middle-income countries were included. There were three studies providing calcium as part of a micronutrient mix: two with fortified biscuits and one with fortified milk. Another trial provided only calcium through fortified muffins and cookies and two trials provided milk fortified with calcium and vitamin D. The only outcome analyzed was growth parameters and no significant effects were observed. The quality of the evidence in both studies was low.

Given the limited evidence available to date and thus the uncertainty in the effects, there is a need for further research to assess the impact of calcium fortification programs, which could be done in the form of pragmatic randomized controlled trials or cluster-randomized trials at the population level.

Foods that are currently fortified with calcium in different countries

We conducted an internet review of commercially available fortified foods with calcium in different countries using commonly available search engines (i.e., Google), which are shown in Table 4. For our search, we used terms, such as "fortified with calcium" or "with added calcium." Commonly used fortification vehicles for calcium included dairy products (cow's milk, yogurt, and cheese) and fruit juices (orange, tangerine, and other). Other products found were: breads, muffins, snacks, breakfast cereals (ready to eat and porridge), cereal bars, infant cereals, sports and energy beverages, plant-based beverages (soy, almond, and rice drinks), infant formulas, tofu, and egg products, among others.

In the United States, ready-to-eat breakfast cereals are widely fortified with several nutrients, including calcium. In Canada, the following foods can voluntarily be fortified with calcium: plant-based beverages, vegetable-based or vegetable products, milk-based products, orange juice, or orange and tangerine juice.[60] In Australia and New Zealand, chewing gum can be fortified with calcium.[61]

Potential weaknesses of multiple simultaneous micronutrient fortification programs

Because of the concerns of several nutritional programs occurring in parallel without proper monitoring, some experts have conducted thorough reviews to map these efforts. For example, a 2019 review identified all the micronutrient programs occurring in Bangladesh, Chile, China, Costa Rica, Guatemala, Malawi, Uganda, and Zambia.[62] Similarly, a review of the SMILING project, a transnational collaboration between Cambodia, Indonesia, Laos PDR, Thailand, and Vietnam, with academic European partners from Europe, conducted a mapping of current fortification programs in these five countries.[63] A list of these programs by country is shown in Table 5. These reviews identified that multiple micronutrient programs are being implemented in these countries with limited coordination and monitoring. Based on these reviews, country-specific recommendations and guidelines were developed to support the implementation, monitoring, and evaluation of the impact of food fortification programs, with certain adaptions by country-specific situations. Among these recommendations was setting a National Food Fortification Board to monitor and harmonize regulations. This board would be important to be established if considering a calcium food fortification program; however, this board should consider all nutritional programs, not only food fortification programs.

Table 4. Examples of commercially available calcium-fortified food items in different countries[a]

Product name	Nutrient(s) added	Examples of brands	Countries	Type of calcium used	Sources
Breads and wheat flour	Thiamin, riboflavin, niacin, folic acid, iron, and calcium	Wonder Aunt Millie's Bimbo Nature's Own	UK (mandatory); USA (voluntary)	Calcium sulfate; calcium stearoyl-2-lactylate; calcium peroxide	www.wonderbread.com www.bimbo.com www.auntmillies.com www.naturesownbread.com
Breakfast cereals (ready to eat)	Calcium	General Mills; Kellogs; Quaker; Kashi; Malt-o-Meal; Nature's Path; NootriToto; NootriMama; Milo, Cheerious, Shredded Wheat, Clusters, Cookie Crisp, Oats And More, Shreddies, Nestlé gofree (Nestle)	More than 87 countries	Calcium pantothenate; calcium carbonate	www.generalmills.com www.kelloggs.com www.quakeroats.com www.kashi.com www.nootriafrica.com www.nestle-cereals.com www.milo.co.nz www.nestle-cereals.com/global
Cereal bars	Calcium, niacin, iron, riboflavin, thiamin, and vitamins B6, B9, B12, and D	Kellogs Quaker Cocoavia Kudos	Australia Canada Ireland New Zealand UK USA	Calcium carbonate	www.nutrigrain.com www.quakeroats.com www.cocoavia.com www.mms.com www.tesco.com
Breakfast cereals	Calcium,niacin, iron, riboflavin, thiamin, and vitamins B6, B9, B12, and D	Weetabix Ace instant porridge	UK South Africa	Calcium carbonate	www.weetabixfoodcompany.co.uk www.acemaizemeal.co.za
Infant cereals	Calcium, iron, zinc, and 12 vitamins	Rice, oatmeal, or wheat cereals (Gerber; Beechnut; Nestlé-Nestum)	Argentina Bolivia Brazil Canada Chile Colombia Costa Rica El Salvador Guatemala Honduras Israel Mexico Nicaragua Panama Peru Puerto Rico USA	Calcium carbonate; tricalcium phosphate	www.gerber.com www.beechnut.com www.nestle.com
Plant-based beverages (soymilk; almond milk; and rice milk)	Calcium and vitamin E	Lactaid; Silk; Califia; Rude Health; Almond Breeze; Rice Dream; SO Delicious; Alpro Bolthouse Farms; Hope; Sesame; Good Karma Tesco Provamel	Australia Canada China Germany Mongolia New Zealand UK USA	Calcium carbonate; calcium phosphate Tri-calcium phosphate	www.goodkarmafoods.com www.silk.com www.califiafarms.zendesk.com www.bluediamond.com www.dreamplantbased.com www.sodeliciousdairyfree.com www.alpro.com www.bolthouse.com www.tesco.com www.provamel.com
Orange juice, tangerine juices, and other juices	Calcium, vitamins D, A, E, C, and omega-3	Florida's Natural; Simply; Minute Maid; Tropicana	USA Canada Israel Somalia	Tricalcium citrate; calcium lactate + calcium phosphate; calcium hydroxide; calcium pantothenate	www.floridasnatural.com www.simplyorangejuice.com www.minutemaid.com www.tropicana.com www.coca-colaproductfacts.com

Continued

Table 4. *Continued*

Product name	Nutrient(s) added	Examples of brands	Countries	Type of calcium used	Sources
Tofu	Calcium and vitamins B2, B6, B12, and D	Nasoya; Mori Nu; Azumaya; House Foods; West Soy	USA	Calcium sulfate; calcium chloride	www.nasoya.com www.morinu.com www.house-foods.com http://www.westsoytofu.com
Infant formulas	Calcium	Similac Neocate	Israel Canada USA	Calcium carbonate; tricalcium phosphate; and calcium glycerophos-phate	www.similac.com www.neocate.com
Dairy products (milk, yogurt, cheese, and malted milk)	Calcium, iron, and vitamin D	Molico (Nestle); Sveltesse (Nestle); Alpina; Alqueria; Lala; Horlick; Ovomaltine	Austria Brazil Colombia Ecuador France Mexico South Korea Switzerland Taiwan UK Venezuela	Carbonate de calcium	www.nestle.com.br/marcas/molico www.nestle.com www.alpina.com www.alqueria.com www.lala.com www.horlicks.co.uk/products www.ovomaltine.com
Obaasima products	Calcium, several vitamins, and iron	N/A	Ghana	N/A	www.obaasimaghana.com/food
Blended food	Calcium, iron, and vitamins A, B12, C, and more	N/A	Malawi	N/A	https://docs.wfp.org/api/documents/WFP-0000100296/download/

[a]Products were found through an internet search using commonly available search engines.

Lessons learned from planning and implementing food fortification programs

Challenges and barriers

When the need and feasibility for fortification are identified in a country or a region, it is important to define the type of program(s) needed. Food fortification is a cost-effective approach to combat micronutrient deficiencies but should be considered as a stand-alone program, as part of a group of simultaneous nutrition interventions, or simply not the best approach to consider for a particular country, age, or sex group. If fortification is one of the selected approaches to tackle micronutrient deficiencies, then the use of more than one fortification vehicle, as well as the chemical form of the fortificants, should be taken into consideration. The selection of the food vehicle is very important and also the feasibility of including the needed nutrient(s) in that food item. Defining the logic model to follow, the technical issues to address, the acceptability of the fortified item, and performing pilot studies should precede the implementation of the program.

The process of implementation of micronutrient food fortification programs is challenging, as there are several steps involved in the process of monitoring and evaluation. A review of available documents about lessons learned from various micronutrient food fortification programs identified the following challenges and barriers:[64–70]

(1) Lack of qualified personnel and lack of training;
(2) Lack of clear guidelines at the country level on implementation, regulatory frameworks, and monitoring and evaluation;
(3) Lack of clarity in the structure and roles of government authorities in regulatory monitoring;
(4) Lack of enforcement of standards by the regulatory agents or political instability, which may be related to perceived political risk in doing so;
(5) Lack of coordination with other public health nutrition interventions;
(6) Lack of communication and education strategies for informing the population about the intervention;
(7) High cost of premix;

Table 5. Summary of micronutrient programs in different countries and measures to coordinate, regulate, and monitor efforts[62,63]

Country	Program	Coordination, regulatory, and monitoring efforts
Bangladesh	• Mandatory fortification of staple foods (salt with iodine, oils with vitamin A, and rice with multiple micronutrients for vulnerable groups) • Supplementation programs (mega doses of vitamin D to children and post-partum women), multiple micronutrient-fortified powders (for young children) • Biofortification (rice with zinc, lentils with zinc and iron, and sweet potato with provitamin A)	No evidence of coordination among programs to prevent or minimize excessive micronutrient intakes
Cambodia	• Fortification of soy and fish sauces with iron • Pilot fortification of rice with multiple micronutrients (iron, folic acid, zinc, vitamins A, B1, B2, B6, and B12) and imported palm oil fortified with vitamin A is available • Voluntary fortification of condiments and complementary foods	
Chile	• Mandatory fortification of staple foods (salt with iodine, wheat flour with iron and B-complex vitamins) • Mandatory complementary feeding programs (for children, pregnant and lactating mothers, and the elderly) • Voluntary fortification of foods (pasta with iron and B-complex vitamins and margarine with vitamin A)	There is a specific regulation for maximum fortification limits of micronutrients in commercial foods
China	• Mandatory fortification of salt with iodine • Voluntary fortification (wheat flour and soy sauce with multiple micronutrients) • Supplementation (capsules with iodized oil for pregnant and lactating mothers in rural areas and in emergencies) • Micronutrient-fortified powders for children	
Costa Rica	• Mandatory fortification of staple foods (salt with iodine, sugar with vitamin A, wheat and maize flours with iron, folic acid, and other B-complex vitamins, rice with folic acid, B-complex vitamins, vitamin E, selenium, and zinc, and milk with vitamin A, iron, and folic acid) • Voluntary fortification of commercial foods (with little supervision) • There are no micronutrient supplementation programs, except as needed on a clinical basis for iron and folic acid to women	There is a food fortification legislation to coordinate all programs although it is not specific to prevent excessive micronutrient intakes
Guatemala	• Mandatory fortification of staple foods (salt with iodine, table sugar with vitamin A, and wheat and maize flours with iron and B-complex vitamins) • Supplementation programs (mega doses of vitamin A to children; multiple micronutrient powders for the point-of-use fortification of foods consumed by children; and iron and folic acid for reproductive women) • Biofortification (beans with iron and corn with zinc)	They have the National Commission for Food Fortification, Enrichment and/or Equivalence (CONAFOR) but this does not take into account micronutrients supplementation programs
Indonesia	• Fortification of wheat flour with iron and zinc, instant noodles with multiple micronutrients and pilot fortification of oil with vitamin A and rice with iron • Voluntary fortification of condiments and complementary foods	

Continued

Table 5. ***Continued***

Country	Program	Coordination, regulatory, and monitoring efforts
Malawi	• Mandatory fortification of staple foods (salt with iodine, wheat flour and maize meal with iron, zinc, vitamin A, folic acid, and other B-complex vitamins, sugar and oil with vitamin A and skimmed milk powder with vitamins A and D) • Supplementation programs (mega doses of vitamin A to children and iron and folic acid to pregnant women) and biofortification (sweet potato with β-carotene)	
Philippines	• Mandatory fortification of staple foods (salt with iodine, rice with iron, wheat flour with iron and vitamin A, sugar and oil with vitamin A) • Voluntary fortification of processed foods (cereal and cereal products with iron and B-complex vitamins, milk and margarine with vitamin A, and juices/flavored drinks/food gels with vitamin C) • Multiple micronutrient powders (for young children and pregnant and lactating women)	
Thailand	• Mandatory fortification of staple foods (salt with iodine, condensed milk with vitamin A), fortification of broken rice with calcium, iron, folate, and vitamin B1 for complementary food. • Voluntary fortification of condiments and complementary foods	
Uganda	• Mandatory fortification of staple foods (salt with iodine, sugar and oil with vitamin A, wheat flour and maize meal with iron, zinc, vitamin A, folic acid, and other B-complex vitamins) • Supplementation programs (mega doses of vitamin A in children, multiple micronutrient powders in children, iron and folic acid supplementation during pregnancy) • Biofortification (beans with iron, sweet potato with provitamin A)	They have established the National Working Group for Food Fortification for the supervision of all fortification activities
Vietnam	• Fortification of fish sauce with iron and wheat flour with multiple micronutrients • Voluntary fortification of condiments and complementary foods	
Zambia	• Mandatory fortification of staple foods (salt with iodine, sugar and margarine with vitamins A and D and wheat flour with iron and B-complex vitamins) • Periodic supplementation programs (mega doses of vitamin A to children, and iron and folic acid to women) • Biofortification (sweet potato and corn with β-carotene)	

(8) Difficulty in reaching the target population (inadequate coverage);
(9) Overconsumption in nontarget groups;
(10) Lack of revisions of the level of the nutrient added to the food, based on the results obtained from the monitoring and evaluation process at the local level;
(11) Use of only one food vehicle to fortify, which may lead to improving intake in some groups but not in others;
(12) Consumption of locally produced unprocessed and unfortified foods in rural villages;
(13) Lack of use of functional indicators or outcomes or lack of available functional indicators for certain micronutrients;
(14) Change in the consumption of the fortified food over time; and
(15) Single nutrient evaluation in the population, without taking into account potential nutrient–nutrient interactions.

How to overcome the challenges

The following are successful approaches for overcoming some of challenges reported in food fortification programs.[71]

Simplify some processes. If there are limited resources, testing of quality control could be done less frequently, and the compliance with the premix addition can be estimated from production/operation records.

Use existing systems/processes. Data on fortified food produced and fortification data can be incorporated into existing health information systems to be used in the future. Also, data on fortification can be added to existing food safety mandates and inspection forms.

Implement effective incentives. Examples include tax waivers for the premix, equipment, and initial costs.

Involve civil society and consumer groups. These could act as watchdogs to improve consumer awareness of noncompliant producers and can support enforcement of regulatory guidance and sharing of data with the government.

Establish guidelines and training for inspection. Delineate the agency in charge of the inspection and the roles and responsibilities of the inspectors. Provide recurrent training and use prepared training modules from international agencies.

Ensure regular reporting by the government. These could include quality reporting, cost analyses, and report cards, based on models established by other organizations. This is regularly done in Peru and Chile for wheat flour fortification.[36]

Design effective communication and social marketing. This requires a study of the identification, acceptance, and demand for fortified foods, including the use and attitudes toward the identified food to fortify, awareness of the importance of the micronutrient to add (in this case calcium), perception and acceptability of food fortification programs, best media to communicate messages that lead to behavioral change, and barriers that must be overcome.[72] At the community level, discussion groups and other measures may be needed for raising awareness and improving knowledge. Also, it should include a creative and attractive logo for branding and as a mark of a quality-controlled product and attractive packaging that reflects the product's quality. Because calcium is mainly voluntarily added to foods, this may be important for such products.

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Author contributions

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Competing interests

The authors declare no competing interests.

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