TRANSFORMING FOOD SYSTEMS TO DELIVER NUTRITIOUS FOODS

THE VITAL ROLES OF FORTIFICATION AND BIOFORTIFICATION

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The Global Alliance for Improved Nutrition (GAIN) is a Swiss-based foundation launched at the UN in 2002 to tackle the human suffering caused by malnutrition. Working with governments, businesses and civil society, we aim to transform food systems so that they deliver more nutritious food for all people, especially the most vulnerable.

ABOUT HARVESTPLUS

HarvestPlus is a CGIAR research programme which aims to improve nutrition and public health by developing and promoting biofortified food crops that are enriched with nutrients. Founded in 2003 and hosted by the International Food Policy Research Institute in Washington, DC, HarvestPlus provides global leadership on biofortification evidence, technology, and policy.

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SUMMARY

An estimated 2 billion people globally are affected by micronutrient deficiencies, while around one third of the global population is at risk of at least one micronutrient deficiency. Micronutrient deficiencies, also known as hidden hunger, can be linked to significant disease burden and economic loss. Food-based approaches to tackling micronutrient deficiencies include improving the micronutrient content of widely consumed foods through large-scale food fortification or biofortification, both of which have been proven to be efficacious, cost-effective, and scalable in increasing micronutrient intakes and improving associated biological outcomes. The literature is replete with evidence on the efficacy, acceptability, and cost-effectiveness of each of these approaches but with few discussions of their complementarity. In this paper, we present a narrative review of food fortification and biofortification and highlight their complementary roles in helping transform food systems to deliver healthy and accessible foods for all.

We find that there are three critical conditions required to maximise the potential impact of these two complementary interventions: 1) programmes aligned with the needs, constraints, and opportunities of the population in terms of consumption patterns, supply chains, and market structures; 2) easy-to-implement, cost-effective, and real-time monitoring of programme delivery, coverage, cost, and nutrient intakes; and 3) a rigorous evidence-base, including lessons learnt, to help inform policy and programme design and assist food systems transformation through the everyday foods consumed by all.

Large-scale food fortification and biofortification are not – individually or together – silver bullets for addressing micronutrient deficiencies, but they represent a golden opportunity to strengthen food systems through their backbones (i.e., staple foods and condiments), to deliver healthier diets for all.

KEY MESSAGES

- Large-scale food fortification and biofortification are proven to be efficacious, effective, acceptable, cost-effective, and scalable interventions to improve nutrient intakes and health outcomes
- By scaling both large-scale food fortification and biofortification, multiple food vehicles can be enriched, coexisting deficiencies can be addressed, and different population segments reached.
- By enriching widely consumed staples and condiments, large-scale food fortification and biofortification can transform food systems without requiring changes in consumer behaviour or significant costs to consumers or producers/processers.

BACKGROUND AND OBJECTIVE

Micronutrient deficiencies (also known as hidden hunger) affect a large proportion of the world's population (an estimated 2 billion people) and can be linked to illnesses, disability, and even death as well as associated economic losses (1). When left unaddressed, hidden hunger limits children's ability to reach their full potential, adults' productivity and income, and countries' economic development and growth for generations to come (2). Widespread deficiencies in key micronutrients such as folate, iodine, iron, vitamin A, and zinc are associated with perinatal complications, poor growth, impaired cognitive development, and increased risk of morbidity and mortality (1). More broadly, six out of top ten risk factors driving the global burden of disease are diet-related (3). Additionally, the effects of the COVID-19 pandemic, coupled with the effects of ever-growing climate crises and conflicts, could exacerbate malnutrition, including micronutrient deficiencies, particularly in low- and middle-income countries (LMICs) and among young children and other vulnerable populations (4–6).

The ideal solution for alleviating hidden hunger is consumption of a varied and diverse diet that provides enough micronutrients to meet an individual's physiological needs. Unfortunately, such diets are often not available or affordable to many households, particularly in LMICs: an estimated 3 billion people cannot afford a healthy diet (7). Food-based approaches, such as the improvement of the micronutrient content of widely consumed foods and condiments through industrial fortification or biofortification, are proven to be efficacious, cost-effective, and scalable solutions to improving micronutrient intakes and associated health outcomes (8).

Large-scale food fortification (LSFF), also known as industrial or mass fortification, is the addition of one or more vitamins and/or minerals to staple foods at the point of processing. LSFF programmes have been in effect since the 1920s, when salt iodisation programmes were initiated in Switzerland and Michigan, USA (9). Based on early successes of salt iodisation in decreasing goitre incidence, food fortification was scaled up and expanded to milk (vitamin D), flour and bread (B vitamins and iron), and other staples and condiments.

Biofortification (also known as nutrient enrichment) of staple crops is the use of conventional crop breeding methods to produce varieties with greater density of bioavailable vitamins and minerals in addition to improved productivity, resistance to biotic and abiotic stresses, climate resilience, and food palatability (10). Biofortification was conceptualised in the 1990s and was consolidated as a programmatic strategy with the formation of the HarvestPlus programme of the Consultative Group on International Agricultural Research (CGIAR) in 2003 (10). Delivery of biofortified planting material through pilot projects began in Uganda and Mozambique in 2006-2007 (11). Subsequently, programmes were established across several countries (including Bangladesh, the Democratic Republic of the Congo, India, Nigeria, Pakistan, Rwanda, and Zambia).

The literature is replete with evidence on the efficacy, potential impact, and cost-effectiveness of LSFF and biofortification (12), but with few discussions of the combination of these two interventions (12,13). In this paper, we present a narrative review of these two approaches to improving diets and elucidate their position as key food systems interventions. In doing so, we additionally seek to clarify the circumstances in which they should be prioritised, individually and in combination. To inform further policy and programme priorities, we finally present the current progress in their scale up and implementation and identify gaps and opportunities.

HOW EFFICACIOUS, EFFECTIVE, AND COST-EFFECTIVE ARE FORTIFICATION AND BIOFORTIFICATION INTERVENTIONS?

LARGE-SCALE FOOD FORTIFICATION

The efficacy (i.e., the performance under ideal and controlled settings) of LSFF has been well-demonstrated (8,14,15). The evidence confirms that the consumption of fortified foods can improve micronutrient status and functional outcomes related to micronutrient deficiencies across different population groups for a range of micronutrients (e.g., iron, folic acid, iodine, vitamin A, vitamin D, and zinc) and food vehicles (e.g., wheat flour, maize flour, rice, salt, oil, sugar, soy and fish sauces, bouillon, and milk) (12).

The effectiveness (i.e., the performance in real world programmatic settings) of LSFF has been similarly demonstrated in high-income countries and to a lesser extent in LMICs. In many high-income countries, LSFF has been credited for its positive impact on various micronutrient deficiency disorders, including the elimination of pellagra and beriberi from flour fortification with B vitamins (niacin and thiamine, respectively) (16,17), reduction in neural tube defects (NTDs) from cereal grain fortification with folic acid (18–20), elimination of rickets from milk fortification with vitamin D (17), and the reduction in goitre prevalence from salt iodisation (21). In LMICs, measurable improvements in micronutrient and health status have also been demonstrated, including reductions in anaemia (from iron fortification), goitre (salt iodisation), NTDs (folic acid fortification), and vitamin A deficiency (22). However, several critical factors that limit effective and sustainable implementation of LSFF programmes have also been identified. These include poor compliance with standards and inadequate monitoring and enforcement, which may limit the potential impact of these programmes and for which there is often limited data available (12).

The benefit-cost ratios — the ratio of the economic benefits relative to the costs — of LSFF are impressive and are the reason it has been consistently ranked as one of the best development interventions (23). With estimates of 30:1 for iodine in salt, 46:1 for folic acid in wheat or maize flour, and 8:1 for iron in wheat or maize flour (24), LSFF ranks higher than immunisation coverage, water and sanitation provision, and malaria control.

BIOFORTIFICATION

The efficacy of biofortified staple crops in reducing micronutrient deficiencies among vulnerable populations in LMICs, namely children under 5, school children, adolescent/young women, and women of reproductive age, is well-demonstrated for several biofortified crops, including iron biofortified beans (25,26), iron-biofortified pearl millet (27), vitamin A-biofortified cassava (28,29), vitamin A-biofortified maize (30–32), and vitamin A-biofortified sweet potato (33–35). Studies have also shown that consumption of biofortified crops resulted in significant improvements in functional, cognitive, and health outcomes such as improved memory and ability to pay attention (36,37) and improved reaction time (37). For iron-biofortified crops, studies have found improved ability to do every day physical tasks, also known as work efficiency (38). For vitamin A-biofortified crops, research has identified reductions in prevalence and duration of diarrhoea for children under five (39); protection from oxidative stress, chronic diseases, and age-related retinal degeneration (30); improved ability to see in dim light (40); and improved vitamin A content of breast milk (41). Efficacy of zinc biofortification (and LSFF) for reducing zinc deficiency is difficult to establish due to the dearth of zinc biomarkers sensitive enough to detect the effect of food-based zinc interventions on zinc outcomes. In lieu of zinc deficiency biomarkers, several health outcomes related to zinc deficiency have been investigated. For example, zinc-biofortified wheat was found to result in significant reductions in morbidity outcomes, such as days spent sick with pneumonia, vomiting, and fever (42). Studies comparing absorption of zinc-biofortified rice and wheat to their zinc-fortified counterparts found zinc biofortification to be at least as good a source of bioavailable zinc as zinc fortification (43–45).

Since biofortification is a more recent intervention than LSFF, and given that effectiveness studies for agricultural-nutrition interventions such as biofortification require significant time and resource investments, the only completed effectiveness studies to date have been on vitamin A-biofortified sweet potato (35,46). These studies found delivery of this biofortified crop to result in significant adoption and consumption thereof; significant increases in vitamin A intakes among women and children; and significant improvement in vitamin A status for children in intervention households.

There is a significant body of *ex ante* cost-effectiveness analyses of several biofortification interventions (see, e.g., (47,48)). These studies, and meta-analysis thereof, found most biofortification interventions to be highly cost-effective according to the World Bank criteria of cost (in USD) per Disability-Adjusted Life Year (DALY) saved (49). Based on such *ex ante* analyses, the Copenhagen Consensus ranked interventions that reduce micronutrient deficiencies, including biofortification, among the highest value-for-money investments for economic development. As per their analysis, for every USD invested in biofortification, as much as 17 USD of benefits may be gained (50).

OVERVIEW OF FORTIFICATION AND BIOFORTIFICATION INTERVENTIONS

WHAT IS THE PREMISE?

Both LSFF and biofortification aim to increase the density and/or bioavailability of specific micronutrients in widely consumed staple foods and condiments. The rationale for focusing on these everyday food vehicles is to reach a large proportion of the population without having to significantly change food production, purchase, and consumption patterns. While these interventions are not targeted to specific population groups, by targeting staple foods they have a high likelihood of reaching vulnerable groups whose diets consist mainly of staple foods that are widely available and affordable but often low in micronutrients and leave them at a high risk of micronutrient deficiencies.

Many commonly consumed food vehicles are fortified and/or biofortified with different nutrients (Table 1). There is some overlap of food vehicles, nutrients, and countries across the two interventions (for example, zinc in wheat flour, rice, and maize and vitamin A in maize). Conversely, other food vehicles are only fortified industrially, such as milk, oil, and salt, or only biofortified, such as beans, cassava, pearl millet, and sweet potato.

There is a wealth of global guidance on how to select food vehicles and set fortification levels in LSFF depending on the population of interest and micronutrient needs and consumption patterns in that population (51). For biofortification, there is a user-friendly tool called the Biofortification Priority Index (BPI) for identifying the most cost-effective and highest-impact country-crop-micronutrient combinations (52). Guidance for setting micronutrient targets for breeding biofortified crops is also available (53).

Table 1. Common nutrients added to food vehicles through fortification and biofortification

Food vehicle	Large-scale food fortification	Biofortification
Beans	-	Iron and zinc
Cassava	-	Vitamin A
Maize	Iron, Calcium, Zinc, Folic acid, Vitamin B12, Vitamin A, Zinc, Thiamine, Niacin, Vitamin B6, and/or Vitamin D	Vitamin A or Zinc
Milk	Vitamin A and/or Vitamin D	-
Oil	Vitamin A, Vitamin D, and/or Vitamin K	-
Pearl millet	-	Iron
Rice	Iron, Folic acid, Vitamin B12, Vitamin A, Zinc, Thiamine, Niacin, and/or Vitamin B6	Zinc
Sweet potato	-	Vitamin A
Salt	Iodine, Iron	-
Wheat	Iron, Calcium, Zinc, Folic acid, Vitamin B12, Vitamin A, Zinc, Thiamine, Niacin, Vitamin B6, and/or Vitamin D	Zinc

HOW ARE FORTIFICATION AND BIOFORTIFICATION DELIVERED WITHIN FOOD SYSTEMS?

LSFF and biofortification interventions are implemented within food supply chains, which is one of the three major components of food systems (in addition to food environments and consumer behaviour) (54). All three components are influenced by various drivers that ultimately determine nutrition and health outcomes. In brief, the food supply chain for staple crops consists of six steps: 1) plant breeding research and development; 2) agricultural production; 3) storage and distribution; 4) processing; 5) packaging and distribution; and 6) retail and markets (Figure 1).

Both LSFF and biofortification have the same ultimate goal and premise of tackling micronutrient deficiencies through improving the micronutrient content of staple foods, as described above. Despite this broader shared programme theory, the ways in which the goal is achieved and the points of entry into the food supply chain differ.

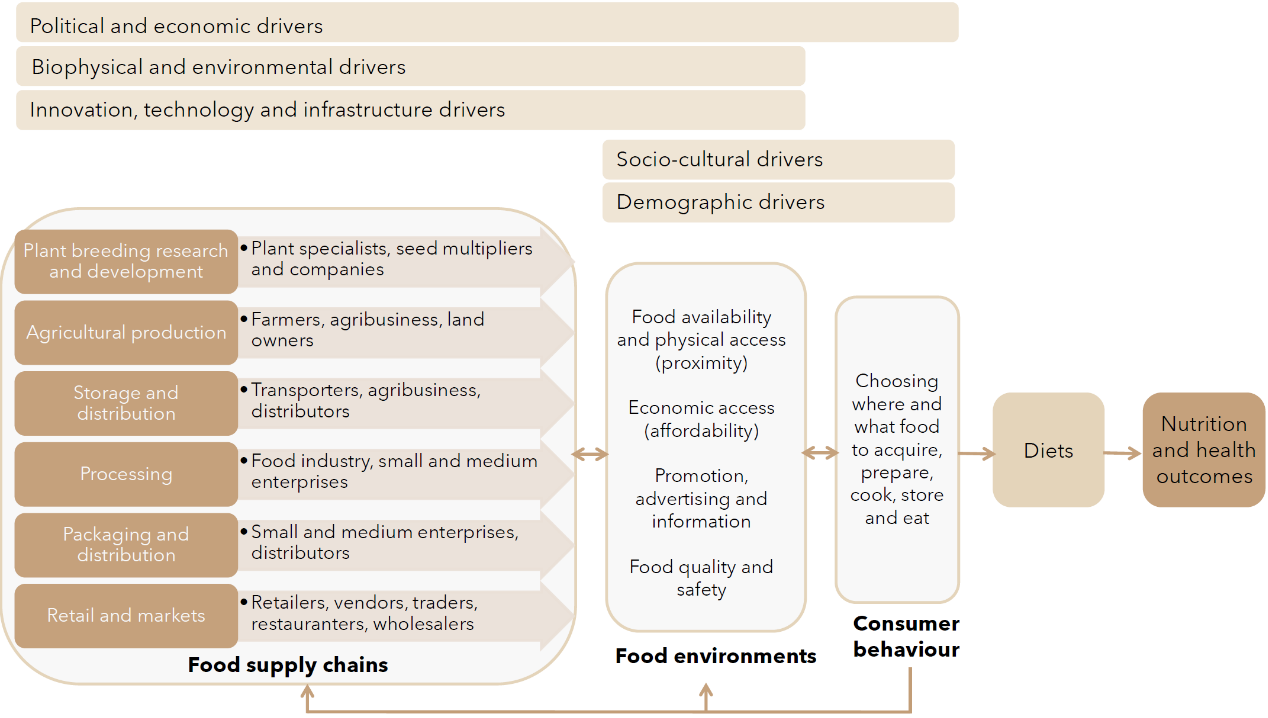

Figure 1. Simplified conceptual framework of foods systems for diets and nutrition focusing on staple crop supply chains (adapted from High Level Panel of Experts 2017 (54))

The LSFF delivery model utilises the existing food supply chain, with one additional step added at the point of processing whereby nutrients (in the form of premix) are added to the foods before they are packaged and sold. After that point, the packaged foods continue through the supply chain to retail outlets, after which the consumer obtains the food (by purchasing it or receiving it formally or informally) and ultimately consumes added nutrients in the foods that they already consume regularly.

LSFF is often ensured by government mandates or legislation (55). The legislation stipulates the categories of foods included in the fortification programme, the level or range of nutrient to be added by industry, the agency responsible for regulation and enforcement of the legislation, and the penalties for non-compliance. As such, fortification programmes often include support for government capacity to monitor and enforce, industry incentives to comply, and consumer engagement to identify and select fortified brands (56,57).

The biofortification delivery model similarly utilises the existing food supply chain. At the point of plant breeding research and development, varieties are bred through conventional plant breeding methods to contain higher levels of certain micronutrients. These varieties are then multiplied and released by licensed seed companies, national systems, and/or humanitarian programs and then acquired by smallholder farmers for planting. The resulting foods produced are higher in micronutrient density for specific nutrients. These foods are then often consumed directly by the farming households and any surplus continues through the food supply chain to retail outlets and markets, where they reach the consumer. As the biofortified food product moves along the food supply chain, mechanisms are needed to identify the crop as being biofortified, especially in cases where the micronutrient trait is invisible (e.g., iron- and zinc-biofortified crops).

For both strategies, an enabling environment can also play a pivotal role in the depth and breadth to which they can be scaled. Such an enabling environment includes – but is not limited to – investments in public research and development (e.g., product development for LSFF, plant breeding for biofortification), setting mandatory minimum standards for micronutrient content of seeds, grains, and foods, and inclusion of foods in input subsidy programmes and procurement policies.

WHERE AND HOW WELL ARE THESE INTERVENTIONS BEING DELIVERED?

LARGE-SCALE FOOD FORTIFICATION

Globally, mandatory or voluntary fortification legislation is currently in effect in 145 countries for salt, 99 countries for wheat flour, 19 countries for maize flour, and 36 countries for oil (58) (Figure 2). Furthermore, 84 additional countries have recently been identified as candidates for new LSFF programmes (56). For illustration, Box 1 draws from available programme records and evaluation evidence (59,60) to illustrate a successful LSFF programme in Costa Rica.

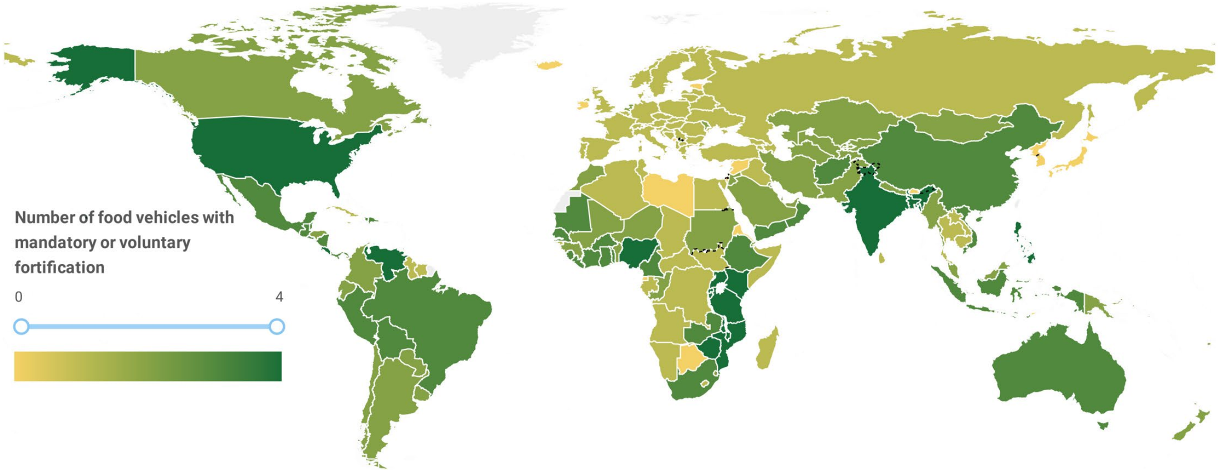

Figure 2. Map of countries with mandatory or voluntary fortification programs (source data: Global Fortification Data Exchange 2020 (58))

Surveys and, recently, household and market coverage data are collected through specific assessments such as the Fortification Assessment Coverage Toolkit (FACT) surveys (61). Quality of fortification is typically defined as compliance with national fortification standards for the type and amount of fortificant added to the food vehicles. Data on fortification quality may be collected as part of regulatory monitoring systems but are not always publicly available, and the frequency and methodology of collection vary widely between countries (62).

The coverage and quality data available for current fortification programmes reveal several gaps in design and implementation, which limit the potential effectiveness of many programmes. These aggregated results are described in detail elsewhere (62); in summary, the potential for impact at the population level varies widely from programme to programme. Specifically, foods that have high population coverage in a fortifiable (i.e., industrially processed) form, like oil/ghee and salt, have the highest potential for impact; however, not all are reaching that potential due to poor quality (either a lack of fortification in general or fortification below standards). Other fortified foods, such as wheat and maize flour, have lower coverage in a fortifiable form, which reduces their potential reach in a population; they also face with similar quality issues to oil/ghee and salt.

The collection and use of data on quality and coverage for programme design and decision making is critical to maximise the impact of LSFF programmes globally.

BOX 1. INGREDIENTS FOR SUCCESSFUL STAPLE FOOD FORTIFICATION IN COSTA RICA

Costa Rica began to address micronutrient deficiencies by adding iodine and fluoride to salt in 1974 and 1989, respectively. In response to the 1996 National Nutrition Survey, which found persistently high levels of micronutrient deficiencies in the country, the government established the cross-sectoral National Micronutrient Commission and worked with the private sector to fortify staple foods. Towards this end, the Ministry of Health carefully selected a basket of staple foods to be fortified with micronutrients that were deficient in the diet. Mandatory fortification of wheat flour began in 1997, maize flour in 1999, milk in 2001, and rice in 2002. The choice of vehicles considered the consumption patterns of the most vulnerable groups. Of note, the government pursued a model where costs were borne by the private sector and the consumer and negotiated with industry to take primary ownership of fortification programmes.

Monitoring data from 2000 to 2012 showed good compliance with fortification mandates for wheat and maize flour and for liquid and powdered milk, at levels that contributed the desired additional nutrient intakes for children (59). Consistent with these observations, the country observed significant declines in the prevalence of anaemia, iron deficiency, and iron-deficiency anaemia between 1996 and 2008. There was equity in this impact – the decreases were more pronounced in rural and urban areas than in metropolitan area of the capital city. An examination of the programme impact pathway illustrated that these changes could be attributed to the programme (60).

This case study illustrates that where LSFF programmes are designed, implemented, and monitored adequately, impact can be achieved (59).

BIOFORTIFICATION

As of the end of 2019, over 340 biofortified varieties of 12 staple crops have been formally released for production in over 40 countries across Africa, Asia, and Latin America (63) (Figure 3). Having kicked off in 2010, delivery efforts for biofortification are relatively new and still at a smaller pilot scale in many countries. Product development, delivery, and implementation research for biofortified crops are spearheaded by the CGIAR's International Potato Center (CIP) and HarvestPlus. In the past decade, these two organisations have been working closely with the public sector, private sector, and UN and NGO partners to bring biofortified planting materials to farming households and biofortified foods to consumers in several countries across Africa, Asia, and Latin America.

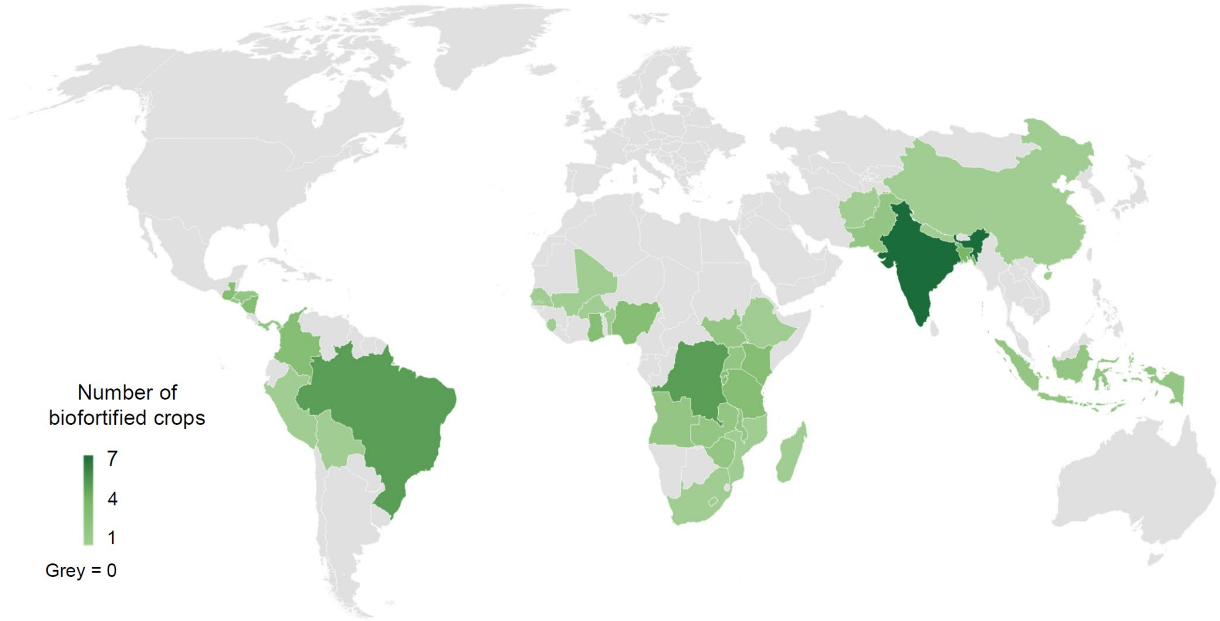

Figure 3. Map of countries with released biofortified crops (data source: (63))

Currently, biofortification has been included in national nutrition policies in Africa (e.g., Malawi, Nigeria, Tanzania, and Uganda) and Asia (e.g., Bangladesh and Pakistan) as well as in agricultural policies in many more countries (64). Additionally, foods made from biofortified foods are now being included in public programmes, such as school feeding programmes in 11 countries (e.g., vitamin-A orange fleshed sweet potato (OFSP) in Gambia, Malawi, Mozambique, and Nigeria (65)). By the end of 2019, an estimated 8.5 million smallholder farming households were reached with biofortified iron beans and pearl millet, vitamin A cassava, maize, and OFSP, and zinc rice and wheat through HarvestPlus-led efforts and an additional 6.8 million farming households with OFSP vines through CIP-led efforts (63).

BOX 2. INNOVATIVE DELIVERY MODELS FOR SCALING IRON-BIOFORTIFIED BEANS IN RWANDA

Rwanda's iron-biofortified bean programme was initiated in 2010 by HarvestPlus, the Rwanda Agricultural Board (RAB), and the International Center for Tropical Agriculture (CIAT). This collaborative programme involved all actors along the bean value chain, from national bean breeders and farmers to retail food companies and consumers, to ensure sustainability and scale. Delivery approaches included sales through authorised agro-dealers; direct marketing by the HarvestPlus country team in local markets; a payback system distributing iron-biofortified bean seeds conditional on the farmer giving back a previously agreed-upon portion of their harvest to the programme, and seed swaps in which local bean grains are exchanged for iron bean seeds. Informal dissemination also occurred through social networks (66,67). A 2019 iron bean adoption study recommended that for long-term adoption, policymakers should focus on: 1) direct marketing to speed initial and continued adoption and 2) payback mechanisms to reduce dis-adoption (66). Social networks increased adoption, suggesting that the positive effect of learning about and obtaining planting material from neighbours outweighs potential negative effects of free-riding or strategic delay (66).

According to monitoring and evaluation data, by the end of 2018, 442,000 households were growing iron beans and an estimated 20% of the beans grown in Rwanda were of iron varieties. A cost-benefit analysis of the programme from 2010-2018 showed that for every dollar invested in the programme, 3 dollars' worth of benefits (in yield and health gains) were accrued (68).

There is strong government endorsement of biofortification in Rwanda, where biofortification is included in the national nutrition action plan. Rwandan authorities recently issued national standards for biofortified bean seeds and grain, which promoted fair trade, improved food processing, and boosted private-sector investment (69). In 2019, a multi-stakeholder platform, consisting of RAB, local non-governmental organisations, and seed multipliers, was developed to encourage and sustain private-sector engagement and further scale up delivery.

ARE THE INTERVENTIONS REINFORCING EACH OTHER?

There are currently no evaluations of the efficacy and cost-effectiveness of combined LSFF and biofortification interventions. However, some modelling studies have explored their potential complementarity. For example, a study in Zambia explored the optimal programme portfolio for tackling vitamin A deficiency by modelling various combinations of two current programmes, i.e., vitamin A-fortified sugar and vitamin A supplementation as part of Child Health Weeks, along with potential new programmes, including vitamin A-fortified vegetable oil and maize flour and vitamin A-biofortified maize (70). The study found that vitamin A oil fortification was the most cost-effective intervention but having both vitamin A-biofortified maize and vitamin A-fortified oil programmes increased coverage (especially in rural areas) without a significant increase in costs. A similar analysis was carried out in Cameroon to identify the most cost-effective combination of vitamin A interventions among vitamin A-fortified oil and bouillon cube, vitamin A-biofortified maize, and periodic vitamin A supplementation for children (13). The study found that in certain regions of the country (e.g., in the South and in urban areas) fortification had the potential to eliminate vitamin A deficiency, while vitamin A supplementation and vitamin A-biofortified maize would be needed to tackle vitamin A deficiency in the maize-consuming Northern region.

There are some inherent differences in how the two interventions are delivered. First and most notably, the entry points into the food supply chain in the food system differ: at processing for LSFF and prior to production for biofortification. Second, LSFF requires more substantial changes in practices among supply chain actors with processors needing to obtain high-quality premix, equipment to fortify, and training to fortify properly and undertake quality assurance and quality control. Comparatively, with biofortification the key behaviour change required is for farmers to choose to grow the biofortified varieties over the non-biofortified varieties they currently grow. In theory, this is simple but may come with its own set of challenges depending on availability of the biofortified planting material and its agronomic competitiveness compared to non-biofortified alternatives; it may also be challenging for aggregators and processors to be able to segregate the biofortified food from the non-biofortified variety if the micronutrient traits are invisible (e.g., for high-iron beans and zinc-biofortified crops).

Third, monitoring of the quality of programme delivery will vary between LSFF and biofortification in terms of how it is done and by whom. For example, in a mandatory LSFF programme, monitoring at production and market level is typically a government mandate whereby checks are done during which food samples are collected and tested to assure that those foods that are required to be fortified do in fact contain the added nutrient in the amounts required by the fortification standards. Comparatively, biofortification is not currently legislated in any country (except for pearl millet iron and zinc minimum breeding standards in India) and instead is included as an action area in national policies and strategies of several LMICs (i.e., 15 in Africa, 3 in Asia, 6 in Latin America and the Caribbean). As such, currently there are no national regulatory requirements exist for standards or the regular collection and testing of samples. However, a voluntary standard for zinc-biofortified wheat, maize, and rice was recently publicly released (71).

There are natural complementarities across the two interventions. For example, micronutrient needs and food consumption patterns (and availability of food vehicles) vary by population, socio-economic status, and geography; therefore, one fortified or biofortified food vehicle is not likely sufficient to fill all nutrient gaps in the population. Rather a combination of foods with different nutrients (biofortified, fortified, and other micronutrient-dense foods such as animal-source foods, nuts, legumes, and fresh fruits and vegetables) is needed. As a result, the decisions around which foods to fortify and which biofortified crop varieties to release should be based on population-specific contextual factors (i.e., micronutrient need, consumption patterns, availability, and affordability) that are regularly reviewed.

Where there is an overlap in food vehicles and/or nutrients, it is important to consider the opportunities in the food supply chain and market structures to decide which intervention(s) to prioritise and/or where there may be benefits to overlapping them. For instance, LSFF may not be the best approach where widely produced staples are consumed without processing or are processed by many local, small-scale producers with limited capacity to fortify. In this context, ensuring availability of biofortified staple crops could help address gaps in micronutrient intakes. While in other instances, some populations that would be reached by each intervention are inherently different, so there is some complementarity in overlapping them. Overall, it is important to increase the nutritional quality of all crops bred and all foods processed, while ensuring that the new varieties of crops are suitable for different agro-ecological environments and a changing climate, and that processed foods are healthy and attractive to consumers. Given ever-changing consumer preferences, trade opportunities, and production technologies and environments, food systems and diets should be continuously evaluated, and additional interventions (or intensity and coverage of existing interventions) should be considered in case of gaps or excesses in any micro- or macronutrients.

Although there are no documented examples, it is plausible that there may be some negative implications of overlapping LSFF and biofortification. For example, if both interventions include the same micronutrients and if other dietary sources provide high levels of that nutrient for some sub-populations and/or in addition to other sources of the nutrient (e.g., supplementation), there could be a risk of excessive intakes in some segments of the population (72,73). This would occur, for example, if industrial fortification with vitamin A was being undertaken for oil and sugar while simultaneously biofortifying maize and cassava with vitamin A – both within the context of a supplementation programme. Such a scenario would indicate gaps in programme design, since added micronutrient contents should consider population and sub-population level needs and potential to benefit.[1]

Further research is needed to understand current food environments, consumers' diets, micronutrient intakes and deficiencies, and their dynamics across time and seasons, rural versus urban areas, and different demographic and socio-economic characteristics, so as to evaluate potential contributions of LSFF or biofortification vis-à-vis current intakes and other complementary programmes. In any case, it is important to remember that both interventions add to micronutrient intakes but are not the only sources in the diet. As such, continual assessment of micronutrient intakes in the total diet and how much each intervention contributes to shifting intakes is needed. In the long term, diet diversification is the goal, and multiple complementary and well-targeted strategies can work towards this end.

CONCLUSIONS

In this paper, we described the centrality of LSFF and biofortification as food systems interventions that can contribute to shifting distributions of nutrient intakes towards adequacy, i.e., "making all boats rise." While neither is a silver bullet – individually or together – for resolving the pervasive problem of hidden hunger, in this paper we have described similarities, differences, and potential synergies.

We conclude by noting three critical ingredients required to maximise the potential impact of these two complementary interventions. First, programmes must be designed in line with the

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[1] It is worth noting that provitamin A carotenoids are highly unlikely to increase the risk of vitamin A toxicity, because although β-carotene can be converted to vitamin A, the conversion of β-carotene to vitamin A decreases when body stores of vitamin A are high (74). Risk of excessive intake is also limited for iron. Globally, infrequent wide-scale implementation of iron supplementation programmes for young children and low compliance in women of reproductive age likely reduces potentially risky overlaps of iron interventions (e.g., fortified complementary foods, plus supplements, plus micronutrient powders in children) (75). Given highly controlled iron absorption and metabolism, excess in other vulnerable groups is low.

needs of the population in terms of consumption patterns, supply chains, and market structures. This is good practice for each intervention but particularly important for delivering the interventions in combination. By scaling both fortification and biofortification, multiple food vehicles can be enriched, coexisting deficiencies can be addressed, and different population segments can be reached. Second, monitoring of programme delivery, coverage, and nutrient intakes (from all dietary sources) is essential. This suggests a need for metrics and methods (31,37). Ideally, coverage indicators for industrially fortified and biofortified foods can be incorporated into routine household surveys, such as Demographic and Health Surveys, Household Consumption and Expenditure Surveys, and Living Standards Measurement Studies, to facilitate monitoring. Third, and finally, national-level guidance should be developed on how best to design and layer micronutrient deficiency mitigation interventions in a manner that builds on their synergies, improves cost-effectiveness, and ensures effective coverage, particularly among those most at-risk of deficiency. Such guidance would be useful for consideration by countries as they develop roadmaps and action plans to transform their food systems by 2030 to deliver nutritious food for all.

To inform policy and programme priorities, further research is needed to conduct implementation and compliance studies and impact evaluations to demonstrate the performance and impact of LSFF and biofortification interventions in combination, specifically quantifying the contribution of these strategies to nutrient intakes in the diet. LSFF and biofortification are not silver bullets, but they represent a golden opportunity to strengthen food systems through their backbones (i.e., staple foods), to deliver healthier diets for all.

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