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Hidden hunger and its prevention by food processing: A review

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Abstract

Hunger means dietary intake that does not provide the kind and quantity of food that is needed for growth, activity and the maintenance of good health. Hunger comes in many guises, four of which (i.e. starvation, undernutrition, micronutrient deficiency and nutrient depleting diseases) serve as indices of hunger in compiling global estimates. Micronutrient deficiency is a global challenge to health. Micronutrient deficiencies (MNDs) have huge impact on health of vulnerable population like women and children and have jeopardized the national economy and prosperity of developing countries. Micronutrients are nutrients required by the body in small amounts for normal physiologic functions. Despite the minuscule demand for micronutrients by the body, their deficiency results in a number of health complications. Globally, more than 2 billion people are affected by micronutrient deficiency where developing world takes most of the burdens. To make things worse, micronutrient deficiency often goes unnoticed for a long time in individuals before symptoms become apparent. Large scale interventions through fortification, biofortification, biotechnology and supplementation of micronutrients to circumvent the devastating consequences of micronutrient deficiencies are showing a great progress by reducing the number of morbidity and mortality attributed to them.

Keywords: Hidden hunger, fortification, diversification, biofortification, supplementation

Introduction

Hidden hunger is a form of undernutrition that occurs when intake and absorption of vitamins and minerals (such as zinc, iodine, and iron) are too low to sustain good health and development. Factors that contribute to micronutrient deficiencies include poor diet, increased micronutrient needs during certain life stages, such as pregnancy and lactation, and health problems such as diseases, infections, or parasites.

Definitions

Hunger: distress related to lack of food

Malnutrition: an abnormal physiological condition, typically due to eating the wrong amount and/or kinds of foods; encompasses undernutrition and overnutrition

Undernutrition: deficiencies in energy, protein, and/or micronutrients

Micronutrient deficiency: (also known as hidden hunger): a form of undernutrition that occurs when intake or absorption of vitamins and minerals is too low to sustain good health and development in children and normal physical and mental function in adults. Causes include poor diet, disease, or increased micronutrient needs not met during pregnancy and lactation

Undernourishment: chronic calorie deficiency, with consumption of less than 1,800 kilocalories a day, the minimum most people need to live a healthy, productive life> Overnutrition: excess intake of energy or micronutrients, and von Grebmer *et al.* (2013) [57].
While clinical signs of hidden hunger, such as night blindness due to vitamin A deficiency and goiter from inadequate iodine intake, become visible once deficiencies become severe, the health and development of a much larger share of the population is affected by less obvious “invisible” effects. That is why micronutrient deficiencies are often referred to as hidden hunger.

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The Global Hidden Hunger Crisis

More than 2 billion people worldwide suffer from hidden hunger, more than double the 805 million people who do not have enough calories to eat (FAO, IFAD, and WFP 2014) [16]. Much of Africa south of the Sahara and the South Asian subcontinent are hotspots where the prevalence of hidden hunger is high. The rates are relatively low in Latin America and the Caribbean where diets rely less on single staples and are more affected by widespread deployment of micronutrient interventions, nutrition education, and basic health services (Weisstaub and Araya 2008) [58]. Although a larger proportion of the burden of hidden hunger is found in the developing world, micronutrient deficiency, particularly iron and iodine deficiency, is also widespread in the developed world.

The nature of the malnutrition burden facing the world is increasingly complex. Developing countries are moving from traditional diets based on minimally processed foods to highly processed, energy-dense, micronutrient-poor foods and drinks, which lead to obesity and diet-related chronic diseases. With this nutrition transition, many developing countries face a phenomenon known as the “triple burden” of malnutrition—undernourishment, micronutrient deficiencies, and obesity (Pinstrup-Andersen 2007) [37]. In higher income, more urbanized countries, hidden hunger can coexist with overweight/obesity when a person consumes too much dietary energy from macronutrients such as fats and carbohydrates (Guralnik *et al.* 2004) [20]. While it may seem paradoxical, an obese child can suffer from hidden hunger.

Micronutrient deficiencies cause an estimated 1.1 million of the 3.1 million child deaths that occur each year as a result of undernutrition (Black *et al.* 2013; Black *et al.* 2008) [40, 46]. Vitamin A and zinc deficiencies adversely affect child health and survival by weakening the immune system. Lack of zinc impairs growth and can lead to stunting in children. Iodine and iron deficits prevent children from reaching their physical and intellectual potential (Allen 2001) [3].

Women and children have greater needs for micronutrients (Darnton-Hill *et al.* 2005) [10]. The nutritional status of women around the time of conception and during pregnancy has long-term effects for fetal growth and development. Nearly 18 million babies are born with brain damage due to iodine deficiency each year. Severe anemia contributes to the death of 50,000 women in childbirth each year. In addition, iron deficiency saps the energy of 40 percent of women in the developing world. Interventions to fight hidden hunger and improve nutrition outcomes generally focus on women, infants, and young children. By targeting these populations, interventions achieve high rates of return by improving health, nutritional status, and cognition later in life.

The most commonly recognized micronutrient deficiencies across all ages, in order of prevalence, are caused by a lack of iodine, iron, and zinc. Less common, but significant from a public health standpoint, is vitamin A deficiency, with an estimated 190 million preschool children and 19 million pregnant women affected (WHO 2009) [24]. Low intakes of other essential micronutrients, such as calcium, vitamin D, and B vitamins, such as folate are also common (Allen *et al.* 2006) [4]. Although pregnant women, children, and adolescents are often cited as populations affected the most by hidden hunger, it impairs the health of people throughout the life cycle.

Table

Hidden Hunger in India (as per Global hunger report)	
Iodine deficiency	25%
Anemia among pregnant women	54%
Anemia among children under 5	59%
Vit.A deficiency	62%

Causes of Vitamin and Mineral Deficiencies

Poor diet is a common source of hidden hunger. Diets based mostly on staple crops, such as maize, wheat, rice, and cassava, which provide a large share of energy but relatively low amounts of essential vitamins and minerals, frequently result in hidden hunger. What people eat depends on many factors, including relative prices and preferences shaped by culture; peer pressure; and geographical, environmental, and seasonal factors. Victims of hidden hunger may not understand the importance of a balanced, nutritious diet. Nor may they be able to afford or access a wide range of nutritious foods such as animal-source foods (meat, eggs, fish, and dairy), fruits, or vegetables, especially in developing countries. In nonemergency situations, poverty is a major factor that limits access to adequate nutritious foods. When food prices rise, consumers tend to continue to eat staple foods while cutting their intake of nonstaple foods that tend to be richer in micronutrients.

Iron Deficiency Anaemia (IDA)

Moderate and severe IDA adversely affects immunity (resistance to fight infections), cognitive and motor development, physical performance (and hence productivity) and reproductive health: (premature birth, low birth weight and perinatal mortality). It is estimated that anaemia is the direct cause of maternal deaths in 20% and contributory cause in another 20%. Apart from dietary deficiency, helminthic infections, inhibitors of iron absorption, in the diet and repeated pregnancies (in women) also contribute.

Iodine Deficiency Disorder (IDD)

Goitre is the clinical manifestation of iodine deficiency disorder. The functional consequences are: permanent brain damage, (cretinism, - mental retardation, and deaf mutism), reproductive failure, and decreased child survival. Milder deficiency also adversely affects mental development.

Vitamin A Deficiency (VAD)

The earliest ocular manifestation of vitamin A deficiency (VAD) is night blindness, and Bitot spots on the white of the eye. Severe vitamin A deficiency leads to keratomalacia (ulceration and sloughing of the cornea) and total blindness. Though kerotamalacia is no longer a public health problem, night blindness is prevalent particularly in pregnant mothers and subclinical deficiency (low Serum levels of Vitamin A), is still encountered. In additionto the ocular manifestations, vitamin A deficiency has been shown to cause growth retardation, decreased resistance to infections, and even death.

B-Complex Deficiencies

Though there is marked dietary, biochemical and clinical evidence of riboflavin (vitamin B_2) deficiency (metabolically a very important vitamin), it has not received adequate attention because its deficiency is neither a killer nor a crippler. Impaired psychomotor performance in school children and adults and impaired reproduction in animals associated with riboflavin deficiency has been reported. There is evidence of dietary and biochemical folic acid deficiency in India. It can cause megaloblastic anaemia due to impaired red cell maturation. Folic acid deficiency has also been implicated in congenital malformation (neural tube defects), Folic acid supplementation in early pregnancy or even pre-pregnant state has been shown to prevent it. Folic acid deficiency leads to raised levels of serum homocysteine – an independent risk factor for cardiovascular disease (CVD). Fragmentary evidence suggests that Indians do tend to have high levels of homocysteine which responds to treatment with folic acid. Till recently, vitamin B_{12} deficiency was not considered to be a problem in India since its daily requirement is only 1 microgram. However, reports of vitamin B_{12}deficiency in developing countries like India and its link with homocysteinaemia, besides megaloblastic anaemia, have started appearing. Both folic acid and B_{12}, besides vitamin B_6 and B_2 are required for homocysteine metabolism.

In view of the rising incidence of CVD in India, B- complex vitamin deficiency needs to be taken more seriously and its link with homocysteinaemia and CVD needs to be investigated. Research is also needed to examine the role and dosage of folic acid for prevention of neutral tube defects- which are not uncommon in India. A balance of folic acid with vitamin B_{12} has to be ensured.

Vitamin D Deficiency

Main function of vitamin D is in bone calcification by facilitating calcium absorption and maintaining blood calcium levels. Since generation of vitamin D in the skin from its precursor 7-dehydrocholesterol is through exposure of skin to sunlight, adequacy of vitamin D in a tropical country like India was assumed. However, recent studies suggest existence of vitamin D deficiency in all age groups in India. As mentioned earlier, osteoporosis associated with calcium and vitamin D deficiency is common in post-menopausal women. Low levels of vitamin D are also associated with chronic diseases like certain malignancies, and chronic inflammatory and autoimmune diseases like type 1 diabetes, and impaired resistance to infections.

Vitamin C Deficiency

Vitamin C is a powerful antioxidant. Dietary vitamin C deficiency does exist, but severe clinical manifestation (scurvy) has become rare. Vitamin C is an iron absorption promoter and hence its deficiency can contribute to IDA. Antioxidants delay degenerative diseases.

Zinc Deficiency

Zinc is essential for growth and development. Zinc supplementation has been reported to help linear growth, reduce severity and duration, of diarrhoeas, and respiratory infections and reduce child mortality.

Consequences of Hidden Hunger throughout life cycle.

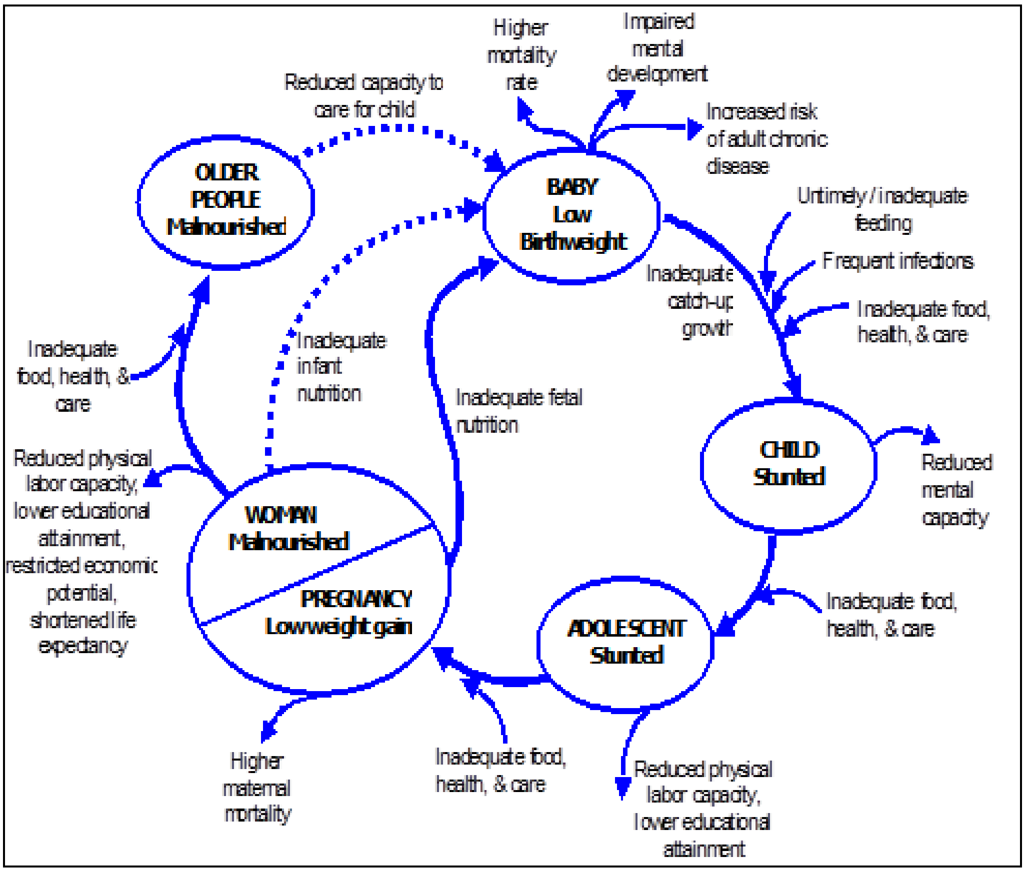

Fig 1

Solutions to Hidden Hunger

Fortifying Commercial Foods

Commercial food fortification, which adds trace amounts of micronutrients to staple foods or condiments during processing, helps consumers get the recommended levels of micronutrients. A scalable, sustainable, and cost-effective public health strategy, fortification has been particularly successful for iodized salt. 71 percent of the world's population has access to iodized salt and the number of iodine-deficient countries has decreased from 54 to 32 since 2003 (Andersson, Karumbunathan, and Zimmermann 2012) [5].

Other common examples of fortification include adding B vitamins, iron, and/or zinc to wheat flour and adding vitamin A to cooking oil and sugar. Fortification may be particularly effective for urban consumers, who buy commercially processed and fortified foods. It is less likely to reach rural consumers who often have no access to commercially produced foods. To reach those most in need, fortification must be subsidized or mandatory; otherwise people may buy cheaper nonfortified alternatives.

Fortification, however, has a number of shortcomings. People may resist fortified foods. For example, up to 30 percent of Pakistanis avoid iodized salt, according to the Micronutrient Initiative, due to a mistaken belief that iodine causes infertility and rumors of a plot to limit population growth (Leiby 2012) [31]. Consumers may also resist using fortified foods due to cooking properties or flavor. From another perspective, it can be difficult to determine the appropriate level of nutrients. Fortificants, the compounds used to fortify foods, may not be stable and may be lost during processing or storage. In addition, bioavailability, the degree or rate at which a substance can be absorbed, may be limited. That said, evidence of the acceptability and efficacy of home fortification continues to grow (Adu-Afarwuah *et al.* 2008; Dewey, Yang, and Boy 2009; De-Regil *et al.* 2013) [2, 36, 12].

Food fortification is a powerful method of reaching out a deficient nutrient to populations, provided the vehicle used for fortification is consumed by the poorest of the poor. This is one successful programme in the country, but its efficiency has to be improved in terms of stability of iodine in the salt, pricing, and outreach.

Foods fortified with micronutrients

Iodine fortification of salt

Salt is one of the most suitable vehicles for iodine fortification and has been successfully used around the world to combat iodine deficiency.

Iodine salts used in fortification and their properties:

Sodium and potassium salts of iodates and iodides are the two chemical forms used in iodization of salt. The level of fortification ranges from 30-200 ppm. The WHO recommends in typical circumstances where Iodine lost from salt is 20% from production to household· Another 20% lost during cooking before consumption. The average salt intake is 10gm/person/day.

Iron Fortified Iodised Salt (IFIS, also called Double Fortified Salt-DFS)

This technology was developed by the National Institute of Nutrition, Hyderabad to address the dual problem of iron and iodine deficiency.

Iron Fortified Wheat Flour (Atta) and Rice

Since staple grains are consumed in substantial quantity, their fortification makes sense. In some countries wheat flour is fortified with iron and other micronutrients. Doubts have been raised about bio-availability of iron from wheat 'atta' because of high phytate (inhibitor of absorption) content. The inhibitory effect of phytate may be bypassed by some potential compounds like Na-Fe-EDTA and or enzyme phytase. The higher cost of this salt may be off-set by better bioavailablity and hence lesser dose of fortification.

For more than a half the population in India, rice is the staple. Fortification of rice has been tried by mixing fortified extruded grains from rice flour with rice (Ultra rice).

Wheat flour fortification

Fortification of wheat flour with thiamin, riboflavin, niacin and iron has been successfully used for a long time. Studies conducted in the U.S. showed good stability of vitamin A added to wheat flour.

Efficacy trials on wheat flour fortification with vitamin A as well as wheat flour with iron are currently underway in the Philippines and Srilanka respectively. Mandatory fortification of wheat with folic acid has been practiced in US and Canada since late 1997. Fortification of wheat flour with folic acid has been successful in South America, Chile and Costa Rica in reducing neural tube defects. Fortification of wheat flour with Zinc sulfate was found to interfere with iron absorption; however zinc oxide did not have such inhibitory effects. In India about 2.2 million tons of wheat flour are fortified. Few states like Madhya Pradesh, Gujarat have initiated recently and few districts in West Bengal have fortified wheat flour since 2000.

Fortification of Cereal Products with Folic Acid

In many countries, cereal products are fortified with folic acid to reduce the incidence of neural tube defects. Folic acidfortification, perhaps along with vitamin B12may also reduce serum homocysteine levels.

Vitamin A fortification

Trials conducted in the Philippines have revealed that fortification of monosodium glutamate with vitamin A produces positive effects on child mortality, and improved growth and haemoglobin levels in children. Later studies with preschool-aged children, who consumed 27 g of vitamin A-fortified margarine per day for a period of 6 months, reported a reduction in the prevalence of low serum retinol concentrations from 26% to 10%. Wheat flour fortified with vitamin A and fed as buns to Filipino school children for 30 weeks had the effect of halving the number that had low liver stores of the vitamin.

Fortification of rice and sugar

It requires more complex technologies. Vitamin A in powdered form is adhered to the sugar crystals with vegetable oil. Vitamins are sprayed on the rice kernels, which are then coated with appropriate food-grade resins to avoid leaching the vitamins when the rice is washed before cooking. Alternatively, simulated kernels can be produced by technologies similar to the those used for noodles. In this case, the vitamins and minerals in powdered form are mixed with the flour used to produce the simulated kernel.

Fortification of Oil with Vitamins A and D

Fats and oils may serve as good vehicles for vitamin A because vitamin A is fat-soluble. Vegetable ghee (hydrogenated vegetable oil) is fortified in India and Pakistan. Margarine is fortified with vitamin A in about 24 countries, including Brazil, Chile, Colombia, Mexico, Indonesia, and many others.

Trials on vitamin A fortified soybean oil is underway in Brazil. In the states of Madhya Pradesh and Rajasthan of India, edible oils fortified with vitamin A and D are being sold through market channel.

Vitamin D fortification

The virtual elimination of childhood rickets in the industrialized countries has been largely attributed to the addition of vitamin D to milk, a practice that commenced in the 1930s in Canada and the United States. However, there are some signs that rickets is re-emerging as a public health problem in these countries. In a recent study of African American women, a low intake of vitamin D fortified milk was found to be a significant predictor of a high prevalence of vitamin D deficiency. Vitamin D fortification of milk also reduces the risk of osteoporosis in the elderly, especially in higher latitude regions where levels of incident ultraviolet light are lower during the winter months.

Fortification of Corn flour

In Venezuela precooked corn flour is fortified with vitamin A, thiamin, riboflavin, niacin and iron. In places like Mexico where corn is the staple food fortification of maize is considered with micronutrients which are deficient in the population. Iron, Zinc and Vitamin B complex are the nutrients added to Maize flour. Maize flour has been fortified with soy protein and tested for brain development in rats. Research is also carried out to fortify corn tortillas both at household and industrial scale.

Fortification of Rice

Rice is an excellent vehicle for fortification as it is the staple in the Asian region. Fortified rice grains are made from rice flour extruded to form a rice kernel shape similar to the appearance of local rice. These fortified rice grains were then blended with regular unfortified rice to reach target levels of vitamin A in the final product. Nutrients considered for rice fortification include iron, folic acid and calcium.

Wheat flour fortification

Wheat is one of the widely produced cereals in the world. Wheat flour is used to make bread, biscuits, pasta and other products. Because of its widespread geographic distribution, acceptance, stability and versatility, wheat flour is a suitable vehicle for delivering micronutrients to mankind.

Micronutrient content of wheat flour:

Wheat is a very good source of B vitamins like B1, B2, niacin, B6, Vitamin E as well as iron and zinc. However since all these nutrients are concentrated in the outer layers, major losses occur in the process of milling. In refined flour the loss is even greater.

Nutrients added to wheat flour:

In developed countries wheat flour is enriched with nutrients equivalent to the loss during the milling process. Vitamin B1, Niacin and iron are often added to enrich wheat flour. However the other nutrients such as B2 are added over and above that lost in milling i.e. fortified. Currently zinc uptake is found to be increased not by adding zinc but by adding phytase, where phytate inhibits zinc absorption.

Food vehicles for fortification

Table 2

Vehicle	(Dis) advantages	Example
Cereals	Consumed in large quantities, throughout the year, and by all members of society, as part of the typical diet	Wheat flour fortification with iron (Chile)
Fats, oils & margarines	Intake generally not sufficient to supply 100% of recommended intake	Margarine fortification with vitamins A & D (in many countries)
Dairy products	Favours mothers and children, but poor, rural populations usually have limited access	Fortification of fluid milk with iron (Argentina)
Condiments	Sugar, spices, starches, sauces consumed regularly through the population, particularly SE Asia	Fish sauce fortification with iron (Thailand), sugar fortification with vit. A (Guatemala)
Value-added products	May be consumed only sporadically by populations with deficiencies	

Dietary diversification

Increasing dietary diversity is one of the most effective ways to sustainably prevent hidden hunger (Thompson and Amoroso 2010) [7]. Dietary diversity is associated with better child nutritional outcomes, even when controlling for socioeconomic factors (Arimond and Ruel 2004) [6]. In the long term, dietary diversification ensures a healthy diet that contains a balanced and adequate combination of macronutrients (carbohydrates, fats, and protein); essential micronutrients; and other food-based substances such as dietary fiber. A variety of cereals, legumes, fruits, vegetables, and animal-source foods provides adequate nutrition for most people, although certain populations, such as pregnant women, may need supplements. Effective ways to promote dietary diversity involve food-based strategies, such as home gardening and educating people on better infant and young child feeding practices, food preparation, and storage/preservation methods to prevent nutrient loss.

Increasing dietary diversity means increasing both the quantity and the range of micronutrient-rich foods consumed. In practice, this requires the implementation of programmes that improve the availability and consumption of, and access to, different types of micronutrient-rich foods (such as animal products, fruits and vegetables) in adequate quantities, especially among those who at risk for, or vulnerable to, MNM. In poorer communities, attention also needs to be paid to ensuring that dietary intakes of oils and fats are adequate for enhancing the absorption of the limited supplies of micronutrients.

Increasing dietary diversity is the preferred way of improving the nutrition of a population because it has the potential to improve the intake of many food constituents – not just micronutrients – simultaneously. Ongoing research suggests that micronutrient-rich foods also provide a range of antioxidants and probiotic substances that are important for protection against selected noncommunicable diseases and for enhancing immune function. However, as a strategy for combating MNM, increasing dietary diversity is not without its limitations, the main one being the need for behaviour change and for education about how certain foods provide essential micronutrients and other nutritive substances. A lack of resources for producing and purchasing higher quality foods can sometimes present a barrier to achieving greater dietary diversity, especially in the case of poorer populations. The importance of animal source foods for dietary quality is increasingly being recognized, and innovative approaches to increase their production and consumption in poorer regions of the world are currently being explored. Efforts are also underway to help poorer communities identify, domesticate and cultivate traditional and wild micronutrient-rich foods as a simple and affordable means of satisfying micronutrient needs.

For infants, ensuring a diet of breast milk is an effective way of preventing micronutrient deficiencies. In much of the developing world, breast milk is the main source of micronutrients during the first year of life (with the exception of iron). Exclusive breastfeeding for the first 6 months of life and continuation into the second year should thus be promoted. Moreover, all lactating women should be encouraged to consume a healthful and varied diet so that adequate levels of micronutrients are secreted in their milk. After the age of 6 months, it is important that the complementary foods provided to breast-fed infants are as diverse and as rich in micronutrients as possible.

Biofortification

Biofortification is a relatively new intervention that involves breeding food crops, using conventional or transgenic methods, to increase their micronutrient content. Plant breeders also improve yield and pest resistance, as well as consumption traits, like taste and cooking time—to match or outperform conventional varieties. To date, only conventionally bred biofortified crops have been released and delivered to farmers. Biofortified crops that have been released so far include vitamin A orange sweet potato, vitamin A maize, vitamin A cassava, iron beans, iron pearl millet, zinc rice, and zinc wheat. While biofortified crops are not available in all developing countries, biofortification is expected to grow significantly in the next five years (Saltzman *et al.* 2013) [45].

Biofortified foods could provide a steady and safe source of certain micronutrients for people not reached by other interventions. In contrast to large-scale fortification, which usually reaches a greater share of urban than rural residents, biofortification first targets rural areas where crops are produced. Marketed surpluses of biofortified crops may make their way into retail outlets, reaching consumers first in rural areas, then in urban ones.

Given that biofortified staple foods cannot deliver as high a level nor as wide a range of minerals and vitamins as supplements or industrially fortified foods can, they are not the best response to clinical deficiencies. However, they can help close the micronutrient intake gap and increase the daily intake of vitamins and minerals throughout a person's life (Bouis *et al.* 2011) [9]. While the evidence on biofortification is not yet complete, several crops (iron beans, maize, pearl millet, rice, sweet potato, and vitamin A cassava) show evidence of improved micronutrient levels (Haas *et al.* 2005; 2011; 2013; 2014; Luna *et al.* 2012; Scott *et al.* 2012; Pompano *et al.* 2013; De Moura *et al.* 2014; -Tanumihardjo 2013; Talsma 2014; van Jaarsveld *et al.* 2005) [11, 21, 22, 23, 38, 22, 51, 56]. Interventions delivering biofortified orange sweet potato significantly improved vitamin A intake of mothers and young children (Hotz *et al.* 2012a; Hotz *et al.* 2012b) [26, 27].

Advantages of Biofortification

It has four main advantages when applied in the context of the poor in developing countries.

- First, it targets the poor who eat large amounts of food staples daily.
- Second, biofortification targets rural areas where it is estimated that 75 percent of the poor live mostly as subsistence or smallholder farmers, or landless laborers. These populations rely largely on cheaper and more widely available staple foods such as rice or maize for sustenance. Despite urbanization and income growth associated with globalization, diets of the rural poor will continue to be heavily based on staple foods like cereals and tuber crops in many regions. Expected increases in food prices, exacerbated by climate change, are likely to increase this reliance on staple foods.
  Supplements or fortified food products are often not widely available in rural areas; in fact, coverage of fortified foods in rural areas may be less than one-third. Therefore, locally produced, more nutritious staple food crops could significantly improve nutrition for the rural poor who eat these foods on a daily basis.
- Third, biofortification is costeffective. After an initial investment in developing biofortified crops, those crops can be adapted to various regions at a low additional cost and are available in the food system, year after year.
- Fourth, because this strategy relies on foods people already eat habitually, it is sustainable. Seeds, roots, and tubers can usually be saved by farmers and shared with others in their communities. Once the high-nutrition trait is bred into the crops, it is fixed, and the biofortified crops can be grown to deliver better nutrition year after year—without recurring costs.

Nutritional bioavailability and efficacy evidence

Biofortified crops can improve human nutrition. To develop evidence of nutritional efficacy, nutritionists first measure retention of micronutrients in crops under typical processing, storage, and cooking practices to be sure that sufficient levels of vitamins and minerals will remain in foods that target populations typically eat (for summary results, see De Moura *et al.* (2015)) [44]. Genotypic differences in retention and concentrations of compounds that inhibit or enhance micronutrient bioavailability are considered. Nutritionists also study the degree to which nutrients bred into crops are absorbed, first by using models, then by direct study in humans in controlled experiments. Absorption is a prerequisite to demonstrating that biofortified crops can improve micronutrient status, but the change in status with long-term intake of biofortified foods must be measured directly. Therefore, randomized controlled efficacy trials are used to demonstrate the impact of biofortified crops on micronutrient status and functional indicators of micronutrient status (i.e. visual adaptation to darkness for vitamin A crops, physical activity and cognition tests for iron crops, etc.).

Iron crops

Iron nutrition research has demonstrated the efficacy of biofortified iron bean and iron pearl millet in improving the nutritional status of target populations. In Rwanda, iron-depleted university women showed a significant increase in hemoglobin and total body iron after consuming biofortified beans for 4.5 months (Haas *et al.*, 2017) [23]. The efficacy of iron pearl millet was evaluated in secondary school children from Maharashtra, India. A significant improvement in serum ferritin and total body iron was observed in iron-deficient adolescent boys and girls after consuming biofortified pearl milletflat bread twice daily for four months. The prevalence of iron deficiency was reduced significantly in the high-iron biofortified pearl millet group. Those children who were iron deficient at baseline were significantly (64%) more likely to resolve their deficiency by six months.

Vitamin A crops

Vitamin A bioavailability studies found efficient conversions from provitamin A to retinol, the form of vitamin A used by the body. Efficacy studies demonstrated that increasing provitamin A intake through consuming vitamin A-biofortified crops results in increased circulating beta-carotene, and has a moderate effect on vitamin A status, as measured by serum retinol. Consumption of orange sweet potato (OSP) can result in a significant increase in vitamin A body stores across age groups (Haskell *et al.*, 2004; Low *et al.*, 2007; van Jaarsveld *et al.*, 2005) [56, 32, 56].

The primary evidence for the effectiveness of biofortification comes from OSP, assessed through a randomized controlled trial. The OSP intervention reached 24,000 households in Uganda and Mozambique from 2006 to 2009 with adoption rates of OSP greater than 60% above control communities (Hotz *et al.*, 2012a, 2012b) [26, 27]. Introduction of OSP in rural Uganda resulted in increased vitamin A intakes among children and women, and improved vitamin A status among children –a decrease in the prevalence of low serum retinol by 9 percentage points.

Women who got more vitamin A from OSP also had a lower likelihood of having marginal vitamin A deficiency (Hotz *et al.*, 2012) [26]. Recent research on the health benefits of biofortified OSP in Mozambique showed that biofortification can improve child health; consumption of biofortified orange sweet potato reduced the prevalence and duration of H.E. Bouis, A. Saltzman Global Food Security (2017), diarrhea in children under five (Jones and de Brauw, 2015) [29].

Biofortified provitamin A maize

It is an efficacious source of vitamin A when consumed as a staple crop. An efficacy study conducted in Zambia with 5–7-year-old children showed that, after three months of consumption, the total body stores of vitamin A in the children who were in the orange maize group increased significantly compared with those in the control group (Gannon *et al.*, 2014) [18]. Consumption of orange maize has been demonstrated to improve total body vitamin A stores as effectively as supplementation (Gannon *et al.*, 2014) [18], and significantly improve visual function in marginally vitamin A deficient children (Palmer *et al.*, 2016) [35].

Zinc crops

Zinc studies have demonstrated that zinc in biofortified wheat is bioavailable (Rosado *et al.*, 2009) [41]. Because plasma zinc concentration, the biomarker widely used to estimate zinc status, has limitations in measuring changes in dietary zinc, foundational research to identify and test more sensitive biomarkers is underway. These biomarkers will be tested in the zinc rice and wheat efficacy trial scheduled for 2017. A recent study showed that DNA strand breaks are a sensitive indicator of modest increases in zinc intake, such as the amount of additional zinc that might be delivered by a biofortified crop (King *et al.*, 2016) [30].

The case of folate and iron in rice

Folate, or vitamin B9, is an essential coenzyme involved in one carbon metabolism. Folate deficiency is associated with a higher risk to newborns of neural tube defects, spina bifida, and anencephaly, and an increased risk of cardiovascular diseases, cancer, and impaired cognitive function in adults. Mandatory fortification of wheat flour with folic acid in the United States in 1998 was followed by a significant reduction in the prevalence of neural tube defects. Folate deficiency also causes widespread megaloblastic anaemia during pregnancy and often exacerbates already existing iron deficiency anaemia.

As with provitamin A, folate levels are very low in rice endosperm and so is the genetic variability of the trait. Thus, folate biofortification is another case for which genetic modification is required. Here, the transformation of two pathway genes from Arabidopsis thaliana shifted folate production to levels in the grains which can be expected to meet the requirements necessary to combat its deficiency. Product development would be required but, inexplicably, has so far not met the interest of donor agencies.

Other results demonstrate that recommendations for folic acid supplementation alone did not appear to succeed in reducing the incidence of open NTDs in Nova Scotia, whereas the fortification of grain products with folic acid did result in a significant reduction in the incidence.

Iron is a redox-active constituent of the catalytic site of heme and non-heme iron proteins. More than one-third of the world’s population suffers from anaemia; half of it caused by iron deficiency. Endemic infectious diseases exacerbate the incidence of iron deficiency anaemia in developing countries. Iron deficiency adversely affects cognitive development, resistance to infection, work capacity, productivity, and pregnancy. Children of anaemic mothers have low iron reserves, requiring more iron than is supplied by breast milk, and suffer from physical growth and irreversible mental development impairment. It is estimated that 800 000 deaths are attributable to iron-deficiency anaemia annually.

Rice endosperm is a very poor source of iron, the variability between cultivars ranging from ca. 1 to 8 ppm. Although a study conducted with rice containing 6 ppm can have a positive impact on nutritional status, there is consensus that significantly higher levels would be very desirable. The lack of adequate variability in iron content of seed calls for transgenic approaches capable of increasing iron partitioning in favour of the grains. However, the knowledge base for this trait is still meagre; 39 genes are thought to control iron homeostasis in rice of which the rate-limiting ones are currently unknown. More research in the field of nutritional genomics is required to answer this question.

In contrast to iron, a significantly higher variability has been found for the zinc content of polished rice grains (G. Barry, P. Virk, IRRI, personal communication) which makes this trait a likely candidate for precision breeding.

Schedule of product release of biofortified crops

Table 3

Crop	Nutrient	Countries of first release	Agronomic trait
Sweet potato	Provitamin A	Uganda, Mozambique	Disease resistance, drought tolerance, acid soil tolerance
Bean	Iron, zinc	Rwanda, Democratic Republic of Congo	Disease resistance, drought tolerance, acid soil tolerance
Pearl millet	Iron, zinc	India	Disease resistance, drought tolerance, acid soil tolerance
Cassava	Provitamin A	Nigeria, Democratic Republic of Congo	Disease resistance
Maize	Provitamin A	Zambia	Disease resistance, drought tolerance
Rice	Zinc, Iron	Bangladesh, India	Disease and pest resistance, cold and submergence tolerance
Wheat	Zinc, Iron	India, Pakistan	Disease and lodging resistance

Supplementation

Supplementation refers to the provision of added nutrients in pharmaceutical form (such as capsules, tablets, or syrups) rather than in food where it is most appropriate for targeted populations with a high risk of deficiency or under special circumstances, such as during pregnancy or in an acute food shortage. Globally, supplementation with iron tablets is the most widely used strategy for the prevention and control of iron-deficiency or anemia in pregnancy. Pregnant women require nearly three times as much iron as non-pregnant women owing to the physiological demands of pregnancy (expanded red-blood-cell volume, the needs of the fetus and placenta, and blood loss at delivery).

This high requirement is unattainable by most pregnant women in developing countries and therefore, iron supplementation is recommended during pregnancy on daily or weekly basis, Iron supplementation is also found to effectively treat severe and moderate anemia in pre-school children. Periodic distribution of high-dose vitamin A supplements, either universally to all preschool children or to targeted high-risk groups, is another most widely practiced intervention for the prevention and treatment of vitamin A deficiency throughout the world. Given every 4-6 months, vitamin A is stored in the liver and mobilized, as needed; to meet the demands of target tissues averts vitamin A deficiency disorders. Similarly, in cases where iodine deficiency disorders are prevalent, iodized oil capsules are commonly used to fulfill daily iodine requirements of the body if iodized salt is unavailable.

Supplementation programmes are used as a short-term intervention measures. It has advantages of rapid coverage of a high-risk population by providing direct a controlled and concentrated dose of the micronutrient to the target group. In addition, supplementation has an immediate impact on micronutrient status and associated functional outcome. Most supplementation programs have been shown to be cost-effective in achieving their nutritional goals and health impacts.

However, inadequate coverage (where deficient individuals are missed or reached irregularly), inability to sustain high coverage over long periods of time as financial, political, or other health priorities change, and poor compliance by target individuals (e.g., iron supplementation during pregnancy) hamper the long term goals. As a result, supplementation is mostly replaced with long-term, sustainable food based measures such as fortification and dietary modification, usually by increasing food diversity.

Conclusion

A lasting end to hunger requires an immediate attention. More than 2 billion people, one-third of the world's population, suffer from micronutrient deficiencies. The consequences of malnutrition and micronutrient deficiencies, beginning with women and their young children account for a large proportion of child and maternal deaths, mental disability, and less productivity of the workforce.

The current mindset of looking at food security only in terms of energy security has to change. Pumping cereals alone to quench hunger will not ensure nutrition and health. The goal should be to ensure a balanced diet adequate in macro- and micronutrients. Laboratory, clinical, and community (operations) -based research is needed to ensure MN security. An optimum mix of food fortification, dietary diversification, biofortification, and supplementation helped in early detection and effective treatment of clinical deficiencies. Extension methodology has to be robust. Media support for creating awareness and compliance is important.

Large scale interventions through fortification, dietary diversification**,** biofortification, and supplementation of micronutrients to circumvent the devastating consequences of micronutrient deficiencies are showing a great progress by reducing the number of morbidity and mortality attributed to them.

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