International Journal of Recent Innovation in Food Science & Nutrition
http://eurekajournals.com/JRIFSN.html

Mitigation of Hidden Hunger through Biofortification: An Appraisal

Jeje, O.A.[1], Oluwafemi G.I.[1], Omowaye-Taiwo O.A[1]

[1]Department of Food Science and Technology, Federal Polytechnic Ado Ekiti, Ekiti State.

Abstract

One form of hunger that is often ignored or overshadowed by hunger related to energy deficits is hidden hunger, also called micronutrient deficiency, which affects some 2 billion people around the world. This shortage in essential vitamins and minerals can have long-term, irreversible health effects as well as socioeconomic consequences that can erode a person's well-being and development. By affecting people's productivity, it can also take a toll on countries' economies. Hidden hunger can coexist with adequate or even excessive consumption of dietary energy from macronutrients, such as fats and carbohydrates, and therefore also with overweight/obesity in one person or community. Poor diet, disease, impaired absorption, and increased micronutrient needs during certain life stages, such as pregnancy, lactation, and infancy, are among the causes of hidden hunger, which may "invisibly" affect the health and development of a population. Possible solutions to hidden hunger include food-based approaches: dietary diversification, which might involve growing more diverse crops in a home garden; fortification of commercial foods; and biofortification, in which food crops are bred with increased micronutrient content. Biofortification is a relatively new intervention that involves breeding food crops using conventional or transgenic methods to increase their micronutrient content. A number of global research showed the ability of biofortified crops to provide a steady and save source of certain micronutrients for people not reached by other interventions. This paper reviews several publications that looked into biofortification with respect to the environment, sustainability, human nutrition, culture and ethics from a variety of places around the world.

Keywords: Hidden hunger, Vitamins, Minerals, Biofortification, Food crops.

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. Its effect can be devastating, leading to mental impairment, poor health, low productivity and even death. Its adverse effects on child health and survival are particularly acute, especially within the first 1,000 days of a child's life, from conception to the age of two, resulting in serious physical and cognitive consequences. Even mild to moderate deficiencies can affect a person's well-being and development. In addition to affecting human health, hidden hunger can curtail socioeconomic development, particularly in low-and middle-income countries (FAO 2013).

A range of interventions are needed to solve the complex problem of hidden hunger. To sustainably tackle the underlying causes will require a multisectoral approach at the national and international levels. National government must take a cohesive approach to confronting hidden hunger, otherwise it will not get the attention it deserves. Only when all ministries, including agriculture, health, child development and education and those handling regulatory affairs, form a united front to improve food and nutrition security will government truly have a chance of succeeding (Black *et al, 2008*).

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 reached 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 retain outlets, reaching consumers first in rural areas, than in urban ones.

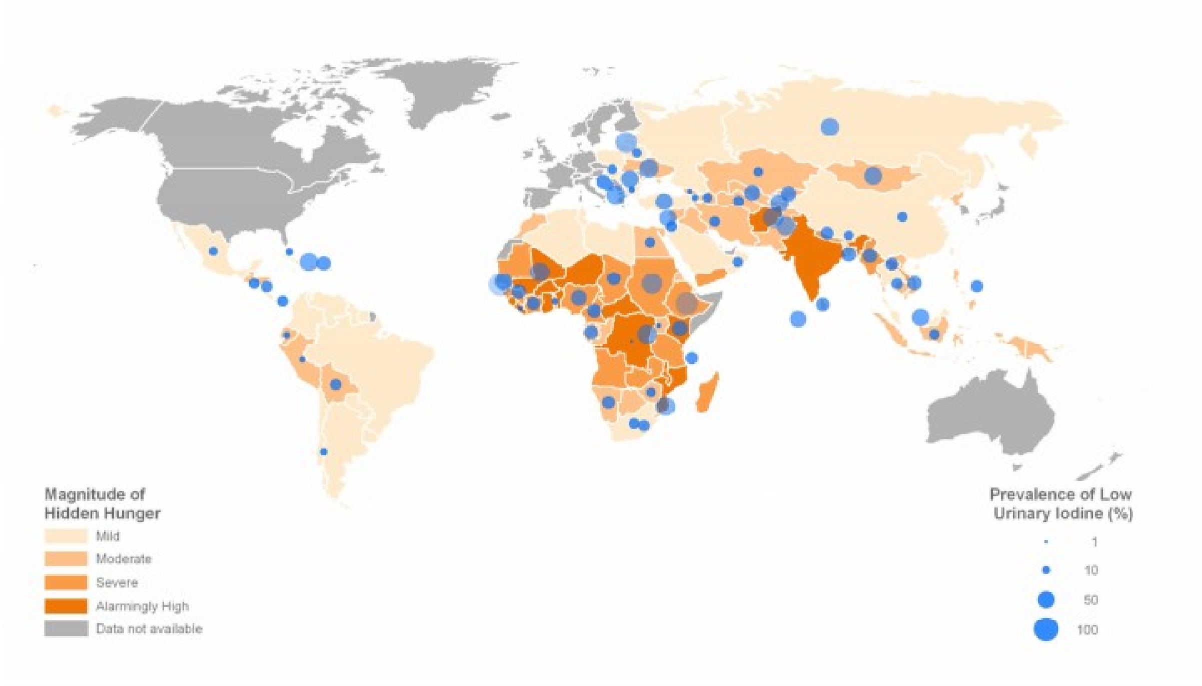
Prevalence, Causes and Consequences of Hidden Hunger

Hotspots of Hidden Hunger

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]. Much of African South of the Sahara and the South Asia subcontinent are hotspots where the prevalence of hidden hunger is high. The rates are relatively low in Latin America and the Carribbean where diets rely less on single staples are more affected by widespread deployment of micronutrient interventions, nutrition education and basic health services (Weisstaub and Araya 2008). Although a large 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 Malnutrition Burden Facing the World

The nature of the malnutrition burden facing the world is increasingly complex. Developing countries are moving from traditional diets based on minimal 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, many developing countries face a phenomenon known as the "triple burden" of malnutrition-undernourishment, micronutrient deficiencies and obesity (Pinstrup-Andersen, 2007). In higher income, more urbanized countries, hidden huger can coexist with overweight/obesity when a person consumed too much dietary energy from macronutrients such as fats and carbohydrates (Cauralnik et al, 2004). While it may seem paradoxical, an obese child can suffer from hidden hunger.



Magnitude of Hidden Hunger (Zinc, Iron and Vitamin A Deficiencies),
Prevalence of Iodine Deficiency

Source: Black *et al., 2013*

Fig 2.1

Prevalence of Hidden Hunger

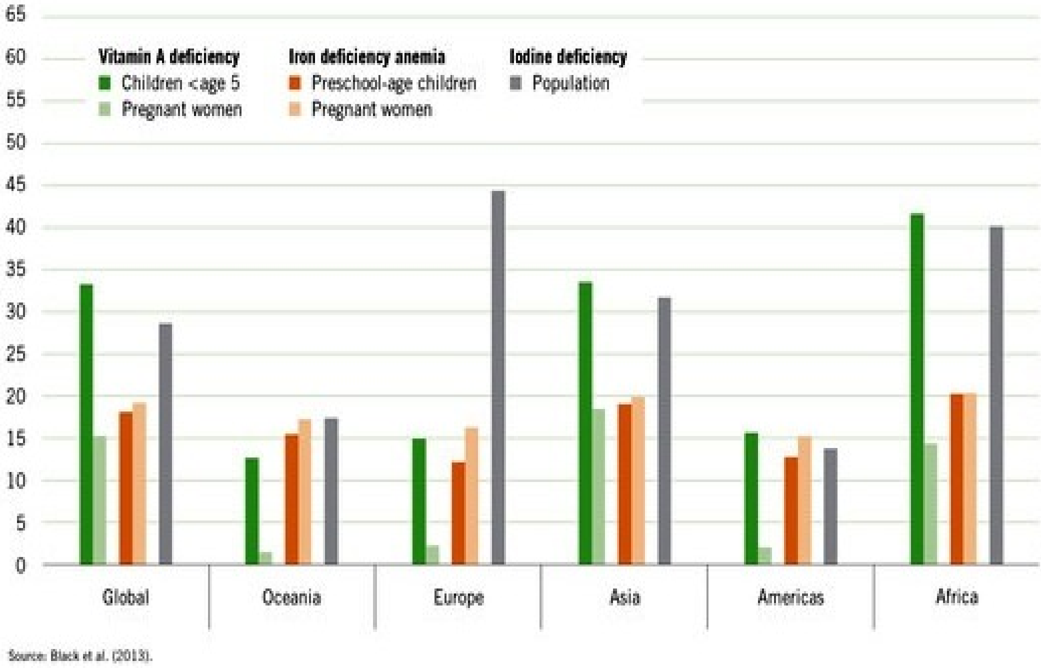


Fig 2.2

Table 2.1

Top 20 Countries Affected by
Multiple Micronutrient Deficiencies

Rank	Country	Hidden Hunger Index Score	Deficiency Prevalence (%)		
			Zinc (Stunting as Proxy for Zinc)	Iron (Anemia Due to Iron Deficiency)	Vitamin A (Low Serum Retinol) (<0.7 µmol/L)
1	Niger	52.0	47.0	41.8	67.0
2	Kenya	51.7	35.8	34.5	84.4
3	Benin	51.3	44.7	39.1	70.7
4	Central African Republic	51.0	43.0	42.1	68.2
5	Mozambique	51.0	47.0	37.4	68.8
6	Sierra Leone	50.0	37.4	37.9	74.8
7	Malawi	49.7	53.2	36.6	59.2
8	India	48.3	47.9	34.7	62.0
9	Burkina Faso	48.3	44.5	45.8	54.3
10	Ghana	47.7	28.6	39.0	75.8
11	São Tomé and Príncipe	47.7	29.3	18.4	95.6
12	Afghanistan	47.7	59.3	19.0	64.5
13	Democratic Republic of the Congo	47.7	45.8	35.7	61.1
14	Mali	46.0	38.5	40.7	58.6
15	Liberia	45.3	39.4	43.4	52.9
16	Côte d'Ivoire	44.0	40.1	34.5	57.3
17	Gambia	43.7	27.6	39.7	64.0
18	Chad	43.3	44.8	35.6	50.1
19	Madagascar	43.0	52.8	34.2	42.1
20	Zambia	42.0	45.8	26.5	54.1

Source: Allen 2001

Causes of Hidden Hunger

Poor Diet

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 preference shaped by culture; peer pressure and geographical, environmental and seasonal factors. Victims of hidden balanced nutritious diet. Not many they be able to afford or access a wide range of nutritious foods such as animal-source foods (meat, eggs, fish and diary), fruits or vegetables, especially in developing countries.

Poverty

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 (Bouis *et al.,* 2011).

Impaired Absorption of Nutrients

Absorption may be impaired by infection or parasites that can also lead to the loss or increased need for many micronutrients. Infections and parasites can spread easily in unhealthy environments with poor water, sanitation and hygiene conditions. Unsafe food handling and feeding practices can further exacerbate nutrient losses.

Diet

Diet also affects absorption. Fat-soluble vitamins such as vitamin A are best absorbed when consumed with dietary fat, while consumption of some compounds such as vitamins or phytates can inhibit iron absorption. Alcohol can interfere with the absorption of micronutrients.

Stages of Life

Life stages such as pregnancy, lactation and infancy are among causes of hidden hunger, which may invisibly affect the health and development of a population.

Consequences of 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 under nutrition (Black *et al*., 2013). 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).

Women and children have greater needs for micronutrients (Darnton-Hill et al. 2005). The nutritional status of women around the time of conception and during pregnancy has long-term effects for foetal growth and development. Nearly 18 million babies are born with brain damage due to iodine deficiency each year. Severe anaemia 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 (UNSCN, 2005).Interventions to fight hidden hunger and improve nutrition outcomes generally focus on women, infants, and young children.

Consequences of Micronutrient Deficiencies Throughout The Life Cycle

Elderly

i. Increased morbidity (including osteoporosis and mental impairment)
ii. Higher mortality rate

Baby

i. Low birth weight
ii. Higher mortality rate
iii. Impaired mental development

Child

i. Stunting
ii. Reduced mental capacity
iii. Frequent infections

iv. (Reduced learning capacity
v. Higher mortality rate

Adolescent

i. Stunting
ii. Reduced mental capacity
iii. Fatigue
iv. Increased vulnerability to infection

Pregnant women

i. Increased mortality
ii. Increased prenatal complications

Adult

i. Reduced productivity
ii. Poor socioeconomic status
iii. Malnutrition
iv. Increased risk of chronic disease

Table 2.2: Selected Micronutrient Deficiencies and their Effects

Micronutrient deficiency	**Effects include**	**Number of people affected**
Iodine	Brain damage in newborns, reduced mental capacity, goitre	1.8 billion
Iron	Anaemia, impaired motor and cognitive development, increase risk of maternal mortality, premature births, low weight, low energy	1.6 billion
Vitamin A	Severe visual impairment, blindness, increased risk of severe illness and death from common infections such as diarrhoea and measles in preschool age children; (in pregnant women) night blindness, increased risk of death	190 million preschool age children; 19 million pregnancy women
Zinc	Weakened immune system, more frequent infections, stunting	1.2 billion

Source: Allen 2001

Addressing Hidden Hunger Challenges

Diversifying Diets

Increasing dietary diversity is one of the most effective ways to sustainably prevent hidden hunger (Thompson and Amoroso, 2010). Dietary diversity is associated with better child nutritional outcomes, even when controlling for socioeconomic factors (Arimond and Ruel 2004). 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 fibre. 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 (FAO 2013). 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.

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 *et al.,*2012).

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 non fortified 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 rumours of a plot to limit population growth (Leiby 2012). Consumers may also resist using fortified foods due to cooking properties or flavour. 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 *et al.,*2009; De-Regil *et al.,* 2013).

Biofortification

Biofortification is a relatively new intervention that involves breeding food crops, using conventional or transgenic methods, to increase their micronutrient content.1 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, biofortificationis expected to grow significantly in the next five years (Saltzman *et al.,* 2013).

Biofortification Efficacy

HarvestPlus leads a global effort to develop and scale up micronutrient-rich staple food crops. The process used is known as biofortification: a cost-effective, sustainable solution that uses conventional plant breeding to increase the density of vitamins and minerals in staple crops consumed widely as part of everyday diets in Africa, Asia, and Latin America and the Caribbean. Micronutrients, although only required by the body in very small amounts, are essential to good health, cognition, and productivity (Bouis *et al*.,2017).

Biofortification helps reduce the widespread gap between micronutrient requirements and intake by increasing the proportion of dietary vitamin A, iron, and zinc—three micronutrients of public health significance globally. Biofortified crops are particularly effective in delivering micronutrients to rural communities, where the majority of lower-income, small-holder farmers who produce staple food crops (and whose families' diets comprise mainly of such crops) reside, and where year-round diverse diets, commercially fortified foods or micronutrient supplements are often inaccessible. Women, young children and adolescent girls are the primary targets of biofortification because they have high nutrient needs that often go unmet. However, since staple foods are consumed widely by all household members, biofortification can provide profound health benefits to the whole family.

By the end of 2017, 6.7 million farming households were reached with biofortified planting material, benefiting about 33 million people, in 14 countries across Africa, Asia, and Latin America and the Caribbean. By 2020, HarvestPlus aims to reach 20 million farming households with biofortified planting material and, by 2030, one billion people are expected to consume biofortified foods globally. In the next five years, HarvestPlus aims to catalyze this scale up by investing in 30 priority countries selected based on their potential to pivot biofortification into the next big movement in food (Garcia-Casal et al., 2017).

Efforts to scale up biofortification are supported by rigorous research and evidence, throughout the entire impact pathway of biofortification. The *African Journal of Food, Agriculture, Nutrition, and Development* and the *Annals of the New York Academy of Sciences* recently devoted special issues to biofortification, which summarize the evidence landscape and suggest the way forward for this agricultural-nutrition intervention (Boy and Miloff, 2009).

HarvestPlus partners with crop breeding centers of the international agricultural research network known as the CGIAR to ensure conventionally bred varieties of nutritious, high-yielding and climate smart staple crops are developed and available for testing and released by national agricultural research systems (NARS). HarvestPlus and its partners measure the impact of biofortified crop consumption on women, adolescent girls and children's nutritional status and functional outcomes, such as cognitive and physical performance. Delivery progress, in outcomes such as adoption and diffusion, are captured through HarvestPlus' rigorous monitoring and evaluation system. Assessments of the effectiveness, cost-effectiveness, and impact of various delivery and promotion strategies are tested along staple crop value chains to share lessons learned and catalyze scale-up.Over the last 15 years, research conducted by HarvestPlus and its partners has demonstrated that:

- Conventional crop breeding can increase nutrient levels without compromising yield
- Extra nutrients in crops measurably improve micronutrient status, health, and cognitive and physical abilities
- Farmers are willing to grow biofortified crops and consumers are willing to eat them
- Biofortification is cost-effective

Conventional Crop Breeding can Increase Nutrient Levels without Compromising Yield

Plant breeders screen thousands of crop varieties stored in global seed banks to discover varieties with naturally higher amounts of essential micronutrients. Then, through collaborations with various breeding centers of the CGIAR, and NARS, these nutrient-rich varieties are used to breed biofortified varieties that are also high-yielding, disease and pest resistant, and climate smart in local agro-ecological conditions.

Planting material for biofortified crops are made available as public goods to national governments, who test and officially release the enriched varieties for planting in their country. Where they are sold by the private sector, they are competitively priced or included in subsidy schemes, so smallholder farmers can afford them (Taleon *et al.,* 2017).

Biofortified crops are bred to fulfill a biologically important portion of the dietary requirement of iron, zinc, or vitamin A of women and children, in populations where these crops are consumed as staples. Based on their usual eating patterns, it is estimated that for children 4 to 6 years old and for non-pregnant, non-lactating women of reproductive age, biofortification provides an additional 35 percent of the Estimated Average Requirement (EAR) of iron in beans and 40 percent in pearl millet; the additional zinc in wheat and rice provides up to 25 percent and 40 percent of the EAR, respectively; and, vitamin A in cassava, maize, and sweet potato provide > 50 percent of the EAR (De Moura *et al.,* 2015).

More than 290 varieties of 12 biofortified crops, including key staples such as iron beans, iron pearl millet, vitamin A cassava, vitamin A maize, vitamin A orange sweet potato (OSP), zinc maize, zinc rice and zinc wheat, have been officially released in over 30 countries. Thousands of varietal lines are currently in testing in these countries, and in over 30 more. As crop development research advances, the nutrient density of crops is further increased, and biofortified varieties are better adapted to the changing climate and consumer preferences.

Extra Nutrients in Crops Improve Health, Micronutrient Status, and Cognitive Abilities

Nutritionists measure the loss and retention of micronutrients in crops under traditional storage, processing and cooking conditions to be sure that sufficient levels of vitamins and minerals remain in foods that target populations typically eat. Nutritionists also study the degree to which nutrients bred into crops are absorbed and utilized by the body, a prerequisite to improving micronutrient status. Randomized controlled efficacy trials are used to demonstrate the impact of biofortified crops on nutritional status and functional indicators of micronutrient status (e.g. visual adaptation to darkness for vitamin A crops; memory, attention, and physical activity for iron crops; and growth and immune competence for zinc crops). Finally, randomized controlled effectiveness studies provide evidence that biofortified crops can improve the nutritional status of populations under typical (non-clinical) conditions. As the case for biofortification builds, rigorous external reviews of the evidence are also taking place. For example, a recent systematic review of three randomized efficacy trials on iron-biofortified crops reinforced the conclusion that iron-biofortified interventions significantly improve iron status—particularly among women and children in low-income communities who need it most [14]. In addition, a World Health Organization (WHO) Cochrane review committee was assembled in 2016 to review the scientific evidence and country experiences of scaling up biofortification. Eight papers were published in the *Annals of the New York Academy of Science* as part of the consultation and a WHO recommendation on biofortification is expected in 2020.

Vitamin A orange sweet potato

Consumption of vitamin A OSP can result in a significant increase in body stores of vitamin A across age groups. The primary evidence for the effectiveness of biofortification comes from vitamin A OSP, assessed through a randomized controlled effectiveness trial. The study reached 24,000 households in Uganda and Mozambique from 2006 to 2009, with vitamin A OSP adoption rates reaching over 60 percent among the beneficiaries. In Uganda, after four growing seasons, serum retinol increased significantly in children under five in the vitamin A OSP intervention group who had low vitamin A status at the beginning of the study. In Mozambique, consumption of vitamin A OSP by children under five significantly reduced the burden of diarrhea, the second leading cause of death in this age group globally; the likelihood of experiencing diarrhea was reduced by 39 percent and duration of diarrhea episodes was reduced by more than 10 percent.

Vitamin a cassava

An efficacy study in Eastern Kenya with 5- to 13-year-old rural schoolchildren demonstrated modest but significant improvement in serum concentrations of retinol and beta-carotene in the vitamin A cassava versus the control group. A recently completed efficacy trial with children under five in rural Nigeria aims to demonstrate the protective effect of vitamin A cassava on vitamin A status.

A consumer acceptance study conducted in two states of Nigeria tested vitamin A cassava *gari* against local *gari.* In the state of Oyo, the local *gari* tested was made with white cassava, and in the state of Imo it was yellow (white cassava mixed with red palm oil), in accordance with regional preferences. In Oyo, consumers preferred *gari* made with light yellow cassava even in the absence of nutrition information. Once consumers received information about the nutritional benefits of vitamin A cassava varieties, light-colored yellow cassava remained the most popular, but *gari* made with deeper-colored yellow cassava was preferred over the local variety. In Imo, on the other hand, in the absence of nutrition information, local *gari* was preferred to the *gari* made with either light- or deeper-colored yellow cassava varieties. However, once consumers were told about the nutritional benefits of vitamin A cassava, *gari* made with the deeper-colored yellow cassava was preferred, highlighting the importance of information campaigns in this area.

Another study on vitamin A cassava, this time in Kenya, found that both the caregivers (18- to 45-year-olds) and children (7- to 12-year-olds) preferred yellow cassava over white cassava because of its soft texture, sweet taste, and attractive color.

Vitamin a maize

An efficacy study in rural Zambia showed that after three months, total body stores of vitamin A in 5- to 6-year-old children eating vitamin A maize increased to a significant extent compared to control group. A larger trial with over 1,000 marginally malnourished 4–8 year-old children in another farming district of Zambia demonstrated that vitamin A maize consumption significantly increased serum beta-carotene concentrations but did not improve serum retinol; significant improvements in other carotenoids (α-carotene, β-cryptoxanthin, and zeaxanthin) were also detected, indicating the potential of vitamin A maize to effect health benefits beyond improvements in vitamin A status, such as protection from oxidative stress, chronic diseases, and age-related retinal degeneration. In this same trial, visual adaptation to darkness was assessed: among children who were vitamin A deficient at baseline, those who consumed vitamin A maize had greater improvement in pupillary responsiveness than those in the control group, improving their ability to see in dim light. Another shorter duration study in the same region showed no increase in mean breast milk retinol concentration among women who consumed vitamin A maize; however, the plausible downward trend in the risk of low milk retinol warrants further investigation.

Iron beans

Biofortified iron beans have been demonstrated to be efficacious in Rwanda, where iron-deficient university women experienced a significant increase in hemoglobin, ferritin, and total body iron after consuming biofortified beans for 4.5 months. Iron beans had a profound effect on cognition: iron deficient women who ate biofortified beans experienced improved memory and ability to pay attention, key skills for optimal performance at school and work. The study also measured physical performance and preliminary results suggest improvements in iron status were accompanied by a reduction in time spent in sedentary activity.

Iron pearl millet

Iron pearl millet was demonstrated to be an efficacious approach to improve iron status in adolescent children through a six-month study conducted in rural Maharashtra, India. After only four months, iron deficiency was significantly reduced, and serum ferritin and total body iron were significantly improved in secondary schoolchildren who consumed iron pearl millet flat bread twice daily. Children who were iron deficient at baseline were 64 percent more likely to resolve their deficiency by six months.Recently published results from the same trial indicate that iron biofortified pearl millet consumption also improved cognitive performance .

Zinc rice

A zinc absorption trial is in progress in Bangladesh, where an efficacy study is also underway to determine the impact of biofortified zinc rice on the nutrition of young children aged 12–36 months. A previous study compared the absorption of zinc from an intrinsically labeled biofortified rice variety to commercially fortified rice in 16 healthy adults. The findings indicated that rice biofortification is as good a source of bioavailable zinc as postharvest zinc fortification.

Zinc wheat

An absorption study among women in Mexico showed that total absorbed zinc was significantly greater from biofortified wheat than from non-biofortified wheat.These findings were corroborated when the absorption of zinc in whole and refined flour from postharvest fortified wheat and agronomically biofortified wheat were tested prior to a randomized controlled efficacy trial in India.Two efficacy trials using wheat biofortified by foliar spraying with zinc fertilizer were recently completed: one with 250 schoolchildren in Bangalore and the other with 3,000 pairs of women and children under two in New Delhi.

Vitamin a orange sweet potato

The randomized controlled effectiveness trial in Mozambique and Uganda (2006–2009) evaluated the impact of two delivery models (one providing more intensive training on nutrition and best agronomics practices than the other) on vitamin A OSP adoption, vitamin A intake, and vitamin A status of beneficiary households. The study found that 61 percent and 68 percent of beneficiary households adopted vitamin A OSP in Uganda and Mozambique, respectively, and no significant differences in the adoption, vitamin A intake, and vitamin A status outcomes resulting from the two delivery model. In 2011, a follow-up study in Uganda found that adoption rates remained high in two of the three study areas and that nutrition information was well retained. The area with the lower adoption rates became a major supplier, but not consumer, of vitamin A OSP. These impact evaluations provided a crucial evidence-base for donors and helped inform the scaling up of biofortification in Uganda. Sensory evaluation studies conducted in Uganda, Tanzania, Mozambique, and South Africa showed that consumers liked the sensory attributes of vitamin A OSP, as well as those of various products made with vitamin A OSP such as bread. Studies in rural Uganda revealed that when nutrition information on the benefits of vitamin A OSP was provided, consumers valued the vitamin A-rich orange varieties more than white ones. Another study conducted in Mozambique also found that consumers valued vitamin A OSP and that the value was influenced by information on nutritional benefits. Collectively, these studies highlight the importance of information campaigns in driving demand for vitamin A OSP.

Vitamin a maize

In Zambia, farmer field day surveys conducted in 2012 and a monitoring survey conducted in 2015 confirmed a strong preference by farmers for both the production and consumption attributes of vitamin A maize varieties compared with conventional white maize varieties. Farmers appreciated the yield, cob size, and cob-filling characteristics of the new varieties, as well as the taste and aroma of vitamin A maize preparations. Nearly all farmers (97 percent) said they would grow vitamin A maize in the next season and that they were planning to plant four times more seed than they did in the previous (2014–2015) season.

A consumer acceptance study conducted in rural Zambia showed that consumers valued *nshima* made with vitamin A maize more than *nshima* from white and yellow maize varieties, even in the absence of nutrition information. When nutrition information was delivered by radio or community leaders, it translated into even greater acceptance of vitamin A maize. The increases in acceptance were similar regardless of the media source, implying that radio—which is significantly less costly than face-to-face messaging—can be used to effectively convey nutrition information. Another study, conducted in rural Ghana, found that consumers valued *kenkey* made with vitamin A maize less than *kenkey* made with either white or yellow maize, but the provision of nutrition information reversed this preference. An information campaign will be key to driving consumer acceptance of vitamin A maize in Ghana.

Iron beans

A study conducted in Rwanda in 2015 assessed the adoption and diffusion rates of iron bean varieties after eight seasons of intensive delivery efforts by HarvestPlus and its partners. Data from this nationally representative study revealed that 28 percent of rural bean-producing households—about half a million households—had planted at least one iron bean variety in at least one of the past eight seasons. In the study season, i.e., the first bean-growing season of 2015, an estimated 20 percent of all bean growers in Rwanda (more than 300,000 rural households) were found to grow iron beans. Further analysis revealed several encouraging findings: awareness of iron beans is high among bean growers in Rwanda, with over two-thirds having heard of iron varieties; diffusion levels are high, with four out of ten farmers receiving planting material from a farmer in their social network; and, the proportion of land farmers allocate to iron beans increases over time (from 48 percent in season one to 70 percent in season six). Additionally, in the study season iron bean varieties made up almost 12 percent of the national bean production, and within households, 80 percent of iron beans produced were used for household consumption.

Consumer acceptance studies conducted in rural Rwanda showed that even in the absence of nutrition information, consumers in the Northern Province liked the sensory attributes of a biofortified red iron bean variety more than a white iron bean or local bean variety. Nutrition information had a positive effect on the premium consumers in urban wholesale, and retail markets were willing to pay for iron beans: when provided, both iron bean varieties were preferred to the local variety. When compared across regions, consumers in the rural Western Province and urban wholesale market also had similar preferences for one of the iron bean varieties tested, suggesting potential for linking demand and supply. Another analysis of multiple sensory attributes revealed several opportunities for marketing of iron beans in both rural and urban markets. Similar studies conducted in the Latin America and Caribbean region, e.g., in Colombia and Guatemala, also revealed positive results for consumer acceptance of iron beans.

Iron pearl millet

A consumer acceptance study of *bhakri* made with iron pearl millet conducted in rural Maharashtra, India, revealed that even in the absence of information about the nutritional benefits, consumers liked the sensory attributes of iron pearl millet grain and the *bhakri* made from it as much as, if not more than, conventional pearl millet grain and *bhakri*. When nutrition information was provided, consumer acceptance and willingness to pay was even greater.

Farmers are Willing to Grow Biofortified Crops and Consumers are Willing to Eat them

Economists conduct studies to understand farmers' willingness to grow biofortified crops and consumers' willingness to pay to purchase them. The aim of these studies is to inform product development, delivery and marketing strategies that will maximize adoption and consumption of biofortified crops. Farmers' willingness to grow biofortified crops is investigated through farmer field day evaluations, monitoring surveys and adoption studies, as well as impact evaluation studies while sensory evaluations (e.g. of appearance, taste, and texture) and willingness to pay studies are conducted to understand consumer acceptance

Biofortification is Cost-Effective

The Copenhagen Consensus ranked interventions that reduce micronutrient deficiencies, including biofortification, among the highest value-for-money investments for economic development. For every dollar invested in biofortification, as much as 17 USD of benefits may be gained.

Ex post (after intervention) cost-effectiveness data on vitamin A OSP from the abovementioned randomized controlled effectiveness trial conducted in Uganda demonstrated that biofortification costs 15-20 USD per Disability Adjusted Life Year (DALY) saved. For other target countries where large-scale delivery efforts have recently started or are about to begin, ex-ante (before intervention) analyses were conducted as well to calculate the expected cost per DALY saved for each context. Results of all these studies and a more recent review of ex-ante analyses pointed out that biofortification is highly cost-effective according to the World Bank criteria. In addition, cost-effectiveness of biofortification is significantly higher in most countries analyzed, when compared to other interventions, such as supplementation and fortification. Exceptions typically involved scenarios with low substitution and/or consumption of the staple crop. Across studies which use health statistics and average country-level data to determine the potential cost-effectiveness of biofortification under 7.

Conclusion

Boifortification is scientifically proven to be a feasible, efficacious, cost effective, sustainable and scalable agricultural-nutrition intervention as it can deliver essential micr-nutrients to malnourished rural and vulnerable population. This can significantly reduce the number of people suffering from hidden hunger and ensure that they have healthy and productive lives, particularly in Africa South of the Sahara and South Asia subcontinent where hidden hunger is more pronounced.

Biofortification is yet to be fully scaled-up in a single country, but much evidence and experience has been assembled to support its eventual effectiveness. As evidence continues to mount, it should be included in the policy framework to address today's major nutrition challenge.

References

Adu-Afarwuah, S.A Lartey, K. Brown, S. Zlotkin, A Briend and K, Dewey (2008): Home fortification of complementary fords with Micronutrient Supplements is Well Accepted and Has Positive Effects on infant Iron Status in Ghana. American *Journal of Clinical Nutrition*, 87(4) 929-938.

Allen, L.H (2001): Biological Mechanisms that might underlie Irons Effects on Foetal Growth and Preterrn Birth. *The Journal of Nutrition* 131:S581-S589.

Andersson, M. V Karumbunathan and M.B Zimmennann (2012) "Global Iodine Status in 2011 and Trends over the past Decade. *The Journal of Nutrition* 142:744-750.

Asare-Marfo .D. Hernington, Birachi E, Birol .E; Cook .K, Diressie M.T, Dusenge .L, Fumes J, Katungi .E. (2016): Assessing the adoption of high iron bean varieties and their impact on iron intakes and other livelihood outcomes in Rwanda. Harvest plus 2016.

Banerji .A, Birol .E, Karandikar .B, Rampal .J. (2016): Information, branding, certification and consumers willingness to pay for high-iron pearl millet. Food Policy 2016 Jul 31; 62: 133-41.

Black, R.E, C.G Victoria, S.P Walker, Z.A Bhutta, P Christian,M, de Onis, M.Ezzati,S Grantham-Mc Gregor, J Katz, R Martorell, R Uauy (2013): Maternal and Child Undernutrition and overweight in low income and middle income countries. *The Lancet* 832(9890) 427-451.

Black, R.E, L.H Allen Z.A Bhuta, L.E, Caufied and M.E Zati (2008): Maternal and Child Undernutrition. The Lancet 371(9608) 243-260.

Bouis H.E, Sceltzman A, Low J, Ball A, Covic .N. (2017): African Journal of Food, Agriculture, Nutrition and Development 2017. 17(2): 11848-64.

Bouis H.E, P. Eozenou and A. Rahman (2011): Food Prices, Household Income and Resource Allocation: Socio-economic perspectiveson their effects on dietary quality and nutritional status.*Food and Nutrition Bulletin* 21(1):S14-23.

Boy E, Miloff .A. Provitamin .A. Carofenold retention in orange sweet potato: A review of the literature. 3: 27-33.

Brnic M, Weg muller R. Melse-Boonstra A; Stomph .T. (2006): Zinc absorption by adults is similar from intrinsically labeled zinc-fortified rice and from rice fortified with labelled zinc sulfate. The Journal of Nutrition 1; 146(1): 76-80.

Darnton-Hill, I.P. Webb, P Harvey, J.M Hunt, N Dalmiya, M Chopra, M.J Ball, M.W Blowem, B de Benoist (2005): Micronutrient Deficiency and Gender: Social and Economic Cost. *American journal of clinical nutrition* 81(5): 1,198S-1,205S.

De- Moura F.F, MiLOFF .A., Boy .E. (2015): Retention of pro vit A Carofenoids in Staple crops targeted for Biofortification in Africa. 29; 55(9): 1246-69.

De-Regil, L.M, P Suchdev, G Vist, S.Walleser and J.P Pena (2013): Home Fortification of Food Health and Nutrition in Children Under Two Years of Age. Evidence-Based Child Health 8:112-201.

Dewey, K, Z Yang and E. Boy (2009): Systematic Review and Meta-analysis of Home Fortification of Complementary Foods. Maternal and Child Nutrition S(4): 283-321. FAO (2013): (Food and Agriculture Organisation of the United Nations). The state of food and Agriculture. Rome http//bit.ly/kAn84P. viewed last on March 21

FAO, IFAD (International Fund for Agricultural Development and WFP (World Food Programme(2014). The state of Food Insecurity in the world 2014. Strenghtening the enabling environment for food security and nutrition. *Rome*: FAO. http:// www.fao.org/3/a-i4030e.pdf. Viewed last on March 21

Finkelstein J.L, Haas J.D, Mehta .S. (2017): Iron Biofortification Staple Food Crops for Improving Iron Status. 30; 44:138-45.

Garcia-Casal M.N, Pena-Rosas J.P, Giyose .B. (2017): Staple crops biofortified with increased vitamins and minerals: considerations for a Public Health Strategy. 1, 1390(1): 3-13.

Guralnik,. J,R.S Eisenstaedt, L Ferrucci, H Clein and R Woodman(2004):Prevalence of anaemia in persons 65 years and older in the united states: Evidence for the high of unexplained anaemia. *Blood* 104(8): 2263-2268

Hoddinott .J, Rosegrant .M, Torero .M. (2012): Investments to reduce hunger and undernutrition. Copenhagen Consensus Challenge Paper 2012.

Leiby, R (2012): "Salt Rumours Add to Health crisis in Pakistan" http://wapo.st/Ir24.to4

Lividini .K, Fiedier J.L, De Moura F.F, Moursi .M, Zeller .M. Biofortification: A review of ex-ante models. *Global Food Security* 2017, Nov 23.

Oparinde A, Bird E, Murzkezi A, Ketsvairo .L. (2016): Consumer willingness to pay for biofortified iron beans. *Canadian Journal of Agricultural Economics* 1: 64(4): 613- 52.

Palmer A.C, Craft N.E, Sclulze K.J, Barffour .M. (2018): Impact of Biofortified maize consumption on Serum Carotenoid concentration in Zambian children. *European Journal of Clinical Nutrition.* 72(2): 301-303.

Pinstrup-Anderson .P. (2007): Agriculture Research and Policy for Better Health and Nutrition in Developing Countries: A Food Systems Approach. Agricultural E conomics 37 (S1): 187-198.

Saltzman,A, .E, Birol, H, Boius, E Boy, F Demoura, Y Islam, and W Pfeiffer (2013): Biofortification; Progress toward a More Nourishing future, *Global Food Security* 2(1): 9-17.

Taleon .V., Mugode .L, Cabrera- Soto .L.(2017): Carofenoid Retention in Biofortified Maize using different Post Harvest Storage Method. *Journal of Asore-Manto Food Chemistry* 1,232:60-6.

Talsma E.F, Brouwer I.D, Verhoef .H, Mbera GNK, Mwangi A.M (2016): Biofortified yellow cassava and vit A status of Kenya children. *American Journal of Clinical Nutrition*. 1,103(1): 258-67.

Tedla .M. Zulu .E, Smale .M, Simpauingwe .E. (2016). An assessment of the Vitamin A maize seed delivery effort is to date- International Food Policy Research Institutes 2016.

Thompson B. and L Amoroso (2010): Combating Micronutrient Deficiencies: Food based Approaches.

UNSCN (United Nations Standing Committee on Nutrition) (2005): The Critical role of Nutrition for Reaching the millennium Development Goals. www.un.org/en/ecosoc/meetings/2005/docs/nut.issue.paper.pdf.

Weisstaub, G and M. Araya (2008): Acute Malnutrition in Latin America: The Challenge of Ending Avoidable Death. *Journal of Pediatric Gastro enterology and Nutrition* 47:S10-14.