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Biofortification of cereal crops: An emerging strategy to overcome hidden Hunger

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Abstract
Bio-fortification of crops is a feasible and most economical approach for overcoming 'hidden hunger'. Increasing the concentration of minerals in edible portions of cereals involves better uptake from soil and improved translocation to grains from leaves and finally enhanced sequestration to endosperm. Genetic diversity can be utilized to enhance micronutrient composition through conventional and modern breeding approaches. The most promising work plan to successfully alleviate micronutrient malnutrition will be to increase mineral content in the crops and simultaneously enhance their bioavailability by reducing anti-nutritional compounds and/or enhancing concentration of mineral absorption promoters. To effectively combat hidden hunger through bio-fortification, even after the development of bio-fortified varieties, it will be essential to address various socio-economical and sociopolitical challenges to popularize their cultivation by farmers and ultimately their consumption by the end users. A multi-tier coordinated strategy will play a pivotal role in overcoming hidden hunger.

Keywords: bio fortification, micronutrient, cereal crops and minerals

Introduction
Micronutrient deficiencies or 'hidden hunger' resulting from unbalanced diets based on starchy staple crops. The inadequate dietary intake of essential micronutrients especially the "big four" iron (Fe), zinc (Zn), vitamin A and iodine is a serious global nutritional problem that is severe among the population of developing countries. Cereal grains are key to fulfill a person's daily energy requirements, but they have very low grain iron, zinc and vitamin A concentrations. Iron and zinc deficiencies are the two major factors for micronutrient malnutrition in the world, affecting an estimated 2 billion people. More than 60% of the world population suffers from micronutrient deficiency. It affects about 38% of pregnant women and 43% of preschool children worldwide and is most prevalent in developing countries. Iron deficiency is one of the most prevalent micronutrient deficiencies, affecting around two billion people globally (WHO, 2016). Children and women in the developing countries are particularly vulnerable with 300 million children and more than 500 million women suffering from iron deficiency anemia worldwide (WHO, 2015).

1. Significance of micronutrient malnutrition
Worldwide, the three most common forms of micronutrient malnutrition (MNM) are dietary deficiencies of iron, vitamin A and iodine. These deficiencies affect at least one third of the world's population, the majority of who live in developing countries. In addition to MNM, about 820 million people in developing countries are under nourished, i.e. ingest fewer calories per day than they require (FAO 2006). It has been estimated that MNM accounts for about 7.3 per cent of the global burden of disease, with iron and vitamin A deficiency ranking among the 15 leading causes of the global disease burden (WHO 2002). According to WHO mortality data, while approximately 0.8 million deaths per year (1.5 per cent of the total) are due to iron deficiency, perhaps the larger impact is the increase in morbidity and the lost of economic productivity, since these people cannot work as hard as those of healthy. Global studies estimate that approximately half of this is due to iron-deficiency anemia (IDA). IDA can affect productivity and cause serious health consequences including impaired cognitive development in children, a weakened immune system and increased risk of morbidity. Recently, low maternal Fe intake has been linked to autism spectrum disorder in their offspring (Schmidt *et al.,* 2014). Nutritional studies suggested that 24–28 mg kg^{-1} Zn and 13 mg kg^{-1} Fe concentration in polished grain is essential to reach the 30% of human estimated

average requirement. On the other hand, one third of the world population is at risk due to low dietary intake of Zn including 2 billion people in Asia and 400 million in sub-Saharan Africa. Zinc deficiency is a major cause of stunting among children. About 165 million children with stunted growth run a risk of compromised cognitive development and physical capability. More than 85% of total body zinc is found in skeletal muscles and bones. The recommended dietary allowances for Zn are 5 mg/day for infants, 10 mg/day for children less than 10 years, 15 mg/day for males more than 10 years, 12 mg/day for females more than 10 years and 15 mg/day for women during pregnancy. Zinc deficiency is responsible for the development of a large number of illness and diseases including stunting of growth, compromised immune system function, cancer, susceptibility to infectious diseases and poor birth outcomes in pregnant women, hair and memory loss, skin problems, weakening of body muscles, infertility in men and pneumonia in children.

2. Nutritional Requirements for People:

Iron: Iron is important both for plants and humans. More than one-third of the world's population suffer from anaemia; half of these cases are caused by dietary deficiency. The incidence of iron deficiency anaemia is higher in developing countries than in developed countries. Iron deficiency adversely affects cognitive development, resistance to infection, working capacity, productivity, and pregnancy. Women of reproductive age are among the most vulnerable to iron deficiency with an estimated 44 per cent of women in developing countries at risk or affected by iron deficiency anaemia. Children of anaemic mothers have low iron reserves, requiring more iron than is supplied by breast milk, and suffer from growth impairment.

Vitamin A: Vitamin A deficiency (VAD) is prevalent among poor persons whose diets are based mainly on rice or other carbohydrate-rich, micronutrient poor staple crops. Vitamin A plays important role in vision, immune response, epithelial cell and bone growth, reproduction, and maintenance of the surface linings of the eyes, embryonic development, and regulation of adult genes. An early symptom of vitamin A deficiency is night blindness.

Iodine: Iodine is an essential component of the thyroid hormones thyroxine and triodotyronine, which regulate growth and development and maintain the basal metabolic rate. However, only 30 per cent of the body's iodine is stored in the thyroid gland, and the precise role of the 70 per cent distributed in other tissues is unknown It is reported that 16.5 million people worldwide suffer from physical and mental retardation and it is likely that another 49.5 million suffer less severe, though still significance, forms of mental impairment due to iodine deficiency.

Zinc: Zinc is an essential co-factor for many cellular enzymes, especially those involved in RNA and DNA synthesis. Zinc deficiency is responsible for impairments of physical growth, immune system, learning ability inadequate repair of DNA damage, which can in turn lead to greater incidence of cancer. Zinc deficiency is directly related to the severity and frequency of diarrhoeal episodes, a major cause of child death. Zinc deficiency affects, on average, one-third of world's population, ranging from 4 to 73 per cent in different countries.

3. Global hunger index: India's position:

India has a "serious" hunger problem and ranks 100th out of 119 countries on the global hunger index behind North Korea, Bangladesh and Iraq but ahead of Pakistan, according to a report. The country's serious hunger level is driven by high child malnutrition and underlines need for stronger commitment to the social sector (International Food Policy Research Institute, IFPRI). India stood at 97th position in last year's rankings. "India is ranked 100th out of 119 countries, and has the third highest score in all of Asia only Afghanistan and Pakistan are ranked worse (IFPRI). At 31.4, India's 2017 GHI (Global Hunger Index) score is at the high end of the 'serious' category, and is one of the main factors pushing South Asia to the category of worst performing region on the GHI this year, followed closely by Africa South of the Sahara. As per the report, India ranks below many of its neighbouring countries such as China (29th rank), Nepal (72), Myanmar (77), Sri Lank (84) and Bangladesh (88). It is ahead of Pakistan (106) and Afghanistan (107). North Korea ranks 93rd while Iraq is at 78th position. IFPRI pointed out that more than one-fifth of Indian children under five weigh too little for their height and over a third are too short for their age. Even with the massive scale up of national nutrition-focused programmes in India, drought and structural deficiencies have left large number of poor in India at risk of malnourishment in 2017(IFPRI).

Country global hunger index scores by rank

As per Global Hunger Index-2017 Report					
Total No. of Countries Ranked	**India's Rank**	**Year wise GHI Scores of India**			
		1992	2000	2008	2017
119	100	46.2	38.2	35.6	31.4
As per Global Hunger Index-2014 Report					
Total No. of Countries Ranked	India's Rank	Year wise GHI Scores of India			
		1995	2000	2005	2014
76	55	26.9	25.5	24.2	17.8

(***Source*:** Global Hunger Index 2017 & 2014 Reports)

To tackle this situation, the application of specific fertilizers has neither been adequate nor effective in supplying the nutrient to the plant, because they are notoriously inefficient and tend to form complexes in soils. Interventions in the past mainly focused on supplementation, food fortification and dietary diversification, which has limited success. Biofortification is a strategy that aims to increase the content of bioavailable micronutrients in crops, particularly staples like rice, maize, wheat, pearl millet and others that sustain human populations in developing countries. Biofortification is a feasible and cost-effective means of delivering micronutrients to populations that may have limited access to diverse diets and other micronutrient interventions. It is the development of nutrient-dense staple crops using the best conventional breeding practices and modern biotechnology, without sacrificing agronomic performance and important consumer-preferred traits.

Iron, zinc, calcium, pro-vitamin A carotenoids, folate, amino acids, prebiotics, etc.

Increasing mineral content of staple food crops through biofortification is the most feasible strategy of combating micronutrient malnutrition. More than 20 million people in farm households in developing countries are now growing and consuming biofortified crops. Additionally, it will also enhance the agronomic efficiency of crops on mineral poor soils. A multipronged strategy towards enhancing mineral content of cereal grains should involve increased uptake of minerals from soil, enhanced partitioning towards grain and improved sequestration in the edible tissues of grains. At the same time, it is essential to improve mineral absorption *in vivo* from cereal-based diets. Both conventional and modern breeding approaches and genetic engineering are being employed for biofortification of crop plants. With increased understanding of mineral uptake and transport mechanisms in plants, it is becoming ever more possible to engineer biofortified crop plants with the ultimate goal of overcoming hidden hunger.

4. Biofortification: an emerging strategy

Biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology. It differs from conventional fortification in that biofortification aims to increase nutrient levels in crops during plant growth rather than through manual means during processing of the crops. Biofortification may therefore present a way to reach populations where supplementation and conventional fortification activities may be difficult to implement and/or limited. Developing biofortified crops also improves their efficiency of growth in soils with depleted or unavailable mineral composition. Conventional breeding and genetic engineering techniques are the two approaches that may be used to biofortify the crops with minerals like iron and zinc. Cereals are the most important source of calories to humans. Rice, wheat and maize provide about 23%, 17% and 10%, respectively, of the calories acquired globally.

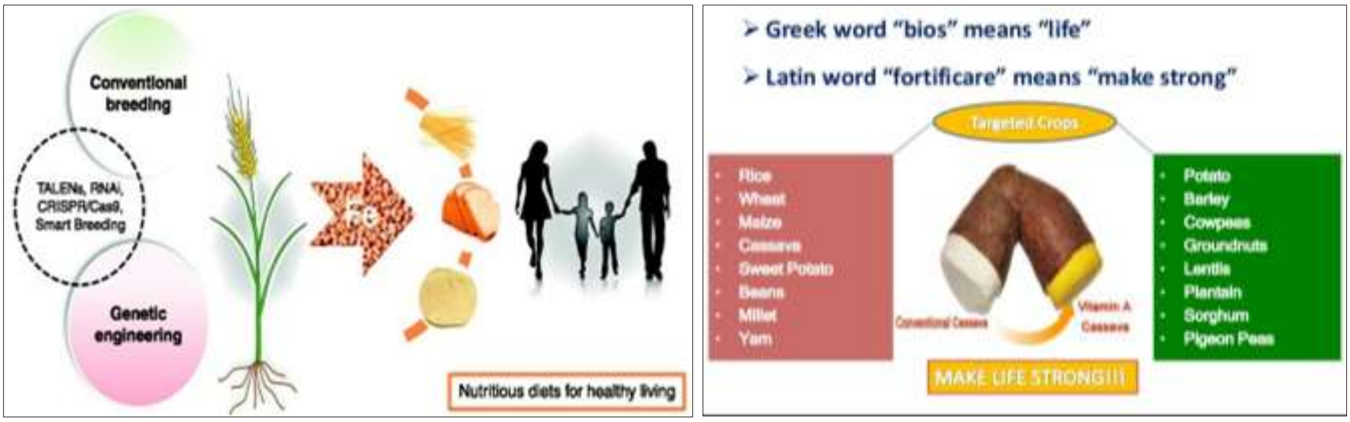


Fig 1: Biofortification

5. Why Biofortification?

Biofortification is important because-

- Fortification and supplementation are shorter term public health interventions; that is most appropriate for acute cases of micronutrient deficiency
- It require infrastructure, sophisticated processing technology, product control, purchasing power, access to markets and health care system for their success
- It is not available to people living in remote areas
- It also requires agronomic practices to increase micronutrient content of cereals -Soil/foliar fertilization which is not feasible, costly, specific agrl. Practices, etc.

6. Biofortification can be achieved through one of three main non-mutually exclusive agronomic methods

1. Application of fertilizer to the soil or leaves
2. Conventional or traditional plant breeding or
3. Genetic engineering, which includes genetic modification and trans genesis.

It is recognized that these agronomic technologies alone or in combination can be applied to improve agricultural productivity and minimize the effects of pests and adverse environmental soil or climate conditions, but potentially produce crops with higher content of selected provitamin A carotenoid or other vitamins or minerals, such as iron or zinc, when all other conditions are optimal for crop growth. Conventional or traditional plant breeding, as well as genetic engineering, could be used alone or in conjunction with soil fertilization or foliar application.

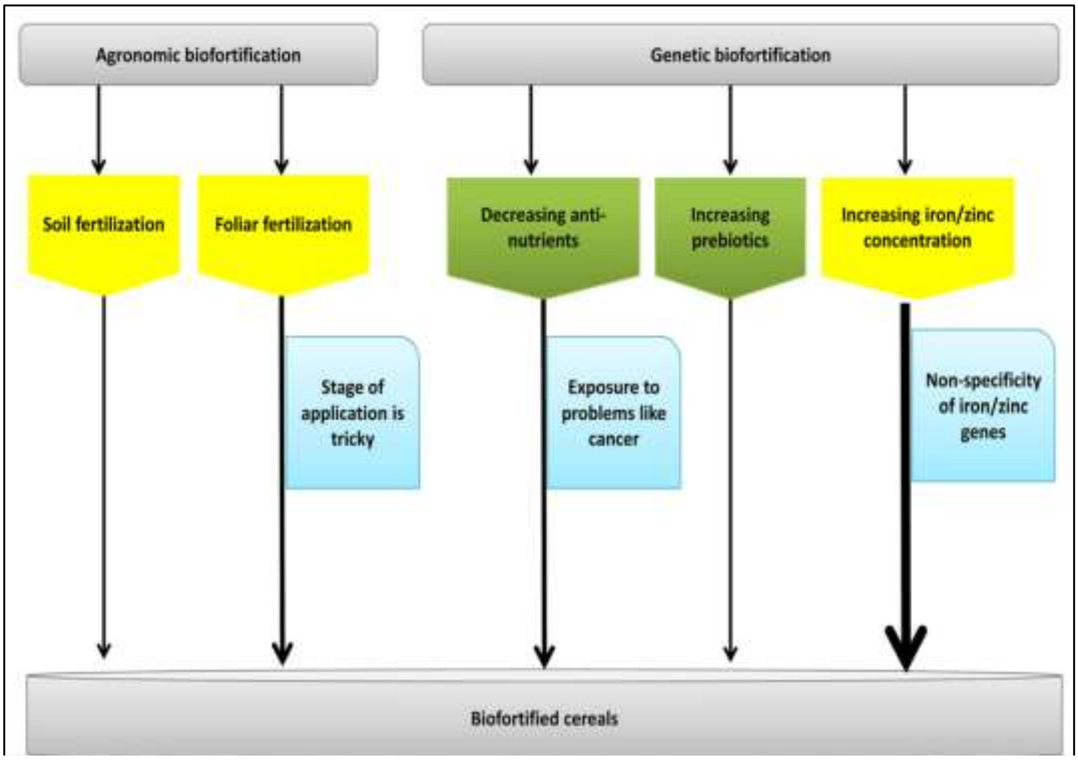


Fig 2: Strategies of cereals biofortification

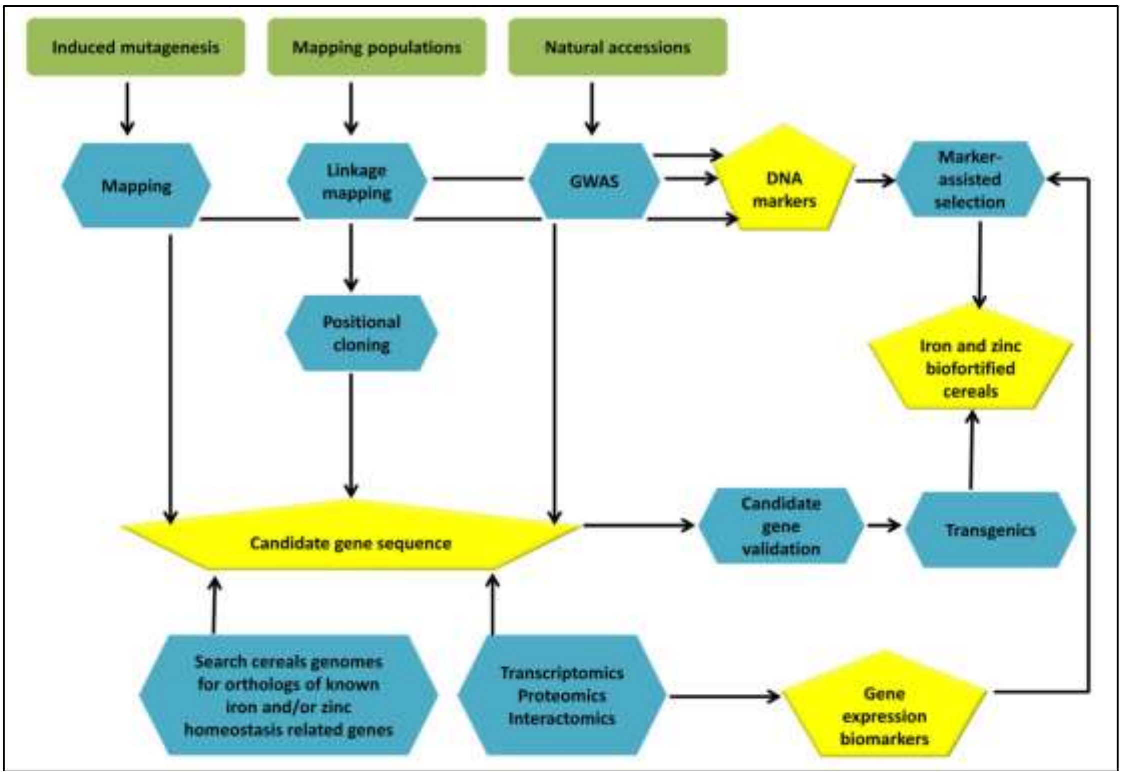


Fig 3: Schematic representation of the genetic approaches aimed at developing iron- and zinc-biofortified cereals

To effectively target biofortification of cereals, five key steps can be targeted. These are

(i) Enhanced uptake from soil,
(ii) Increased transport of micronutrients to grains,
(iii) Increased sequestration of minerals to endosperm rather than husk and aleurone,
(iv) Reduction in antinutritional factors in grains and
(v) Increase in promoters of mineral bioavailability in grains

8. Criteria for Biofortification of cereals

- Crop productivity must be maintained /enhanced to guarantee farmer acceptance (high yielding)
- Micronutrient enrichment levels must have significant impact on human health (effective)
- Enriched levels must be relatively stable (stability)
- Bioavailability in enriched lines must be tested in humans to ensure that they improve the micronutrient status of people preparing and consuming them (efficacious)

- Consumer acceptance has to be tested (taste and cooking quality)

9. Steps in Biofortification
- Identification of genetic variability within the range that can influence human nutrition
- Introgressing this variation into high yielding, stress tolerant genotypes possessing acceptable end-use quality attributes
- Testing the stability of micronutrient accumulation across the target environment
- Large scale deployment of seed of improved cultivars to farmers

Simplified diagram of the pathway for bio-fortified crops (Harvest Plus, 2009)

Harvest Plus: Harvest Plus is a global alliance of institutions and scientists seeking to improve human nutrition by breeding new varieties of staple food crops consumed by the poor that have higher levels of micronutrients, through a process called biofortification. It is an initiative of the Consultative Group on International Agricultural Research. It is coordinated by the International Centre for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI).

A selection of staple crops in development for improved nutrient composition

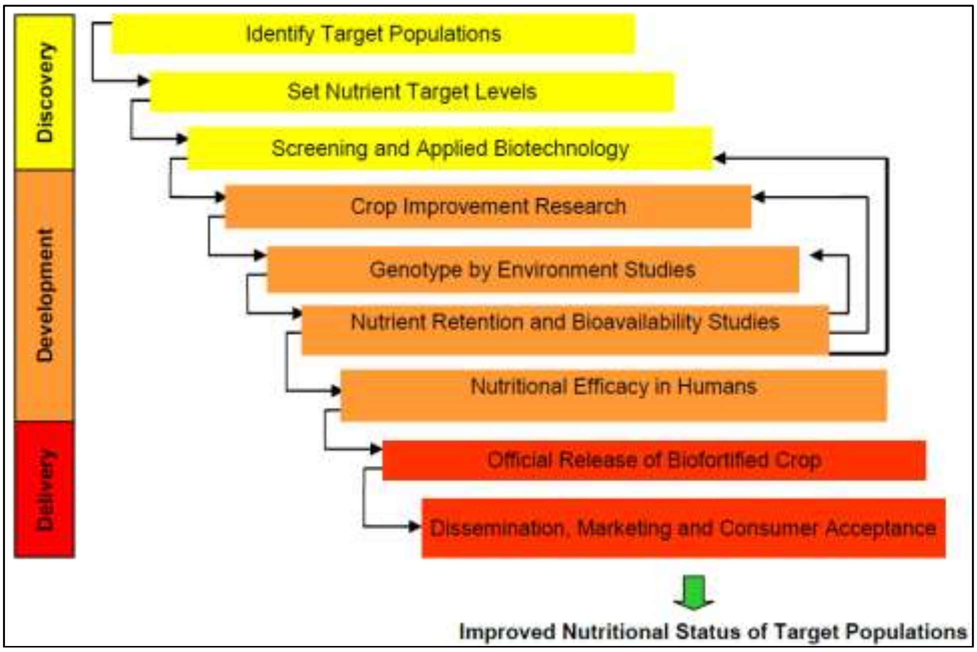
Trait	Crops
Beta-carotene (vitamin A)	Mustard, potato, tomato
Vitamin E	Canola, corn, soybean
Vitamin C	Corn, strawberry
Iron availability	Lettuce, rice, corn
Essential amino acids	Canola, corn, potato, sorghum
Protein content/quality	Bahiagrass, canola, corn, potato, rice, soybean
Fructan (fiber)	Chicory, corn, potato, sugar beet

Role of Harvest Plus

Since 2004, Harvest Plus, a Challenge Program of the Consultative Group on International Agricultural Research, has led the charge to breed and disseminate micronutrient-rich bio fortified crops. Harvest Plus is an inter-disciplinary program of plant breeders, molecular biologists, nutritionists, economists, and communication and behavior change experts.

It focuses on three critical micronutrients lacking in the diets of the poor: vitamin A, zinc and iron. Through a global alliance now involving more than two hundred scientists, Harvest Plus is bio fortifying seven staple food crops that are critical in the diets of the poor in developing countries.

Steps



Stage 1: Identifying Target Populations and Staple food Consumption Profiles: Overlap of cropping patterns, consumption trends, and incidence of micronutrient malnutrition determine target populations. This in turn determines the selection and geographic targeting of focus crops.

Stage 2: Setting Nutrient Target Levels: Nutritionists work with breeders to establish nutritional breeding targets based on the food intake of target populations, nutrient losses during storage and processing, bioavailability of nutrients related to the presence or absence of complementary compounds. Setting target levels includes:

Crop specific factors
- Per capita consumption levels of the food staple
- Baseline micronutrient content of the crop
- Retention of nutrients in storage, processing, and cooking

Target group specific factors
- Age of target group

- Physiological state, such as growing child, pregnancy or lactation
- Bioavailability of iron or zinc or projected retinol equivalency (provitamin A)
- Nutrient intake from other foods.

Stage 3: Screening and Applied Biotechnology: The global germplasm banks of the CGIAR institutes and the germplasm banks held in trust by national partners provide a reservoir of staple crops germplasm for screening by Harvest Plus. Genetic transformation provides an alternative strategy to incorporate specific genes that express nutritional density.

Stage 4: Crop Improvement: Crop improvement along with nutritional bioavailability and efficacy make up the two largest stages of all research activities. Crop improvement includes all breeding activities falling within a product concept that produces varieties containing those traits that (in target populations, in target areas) improve nutrient content while giving high agronomic performance, and preferred consumer quality. Biofortification of Crop Improvement is divided into three phases:

- Early Stage Product Development and Parent Building (phase 1)
- Intermediate Product Development (phase 2)
- Final Product Development (phase 3)

Stage 5: Genotype by Environment (GxE) Interactions on Nutrient Density: Germplasm is tested in target countries for their suitability for release. Genotype x environment interaction can greatly influence genotypic performance across different crop growing scenarios. Harvest Plus researchers are looking for high and stable expression of high micronutrient content across environments as well as alternative farming practices that enhance the uptake of nutrients in the edible portion of the crop.

Stage 6: Nutrient Retention and Bioavailability: Harvest Plus nutrition teams are measuring the effects of usual processing, storage and cooking methods on micronutrient retention for biofortified crops and evaluating practices that could be used by target populations to improve retention.

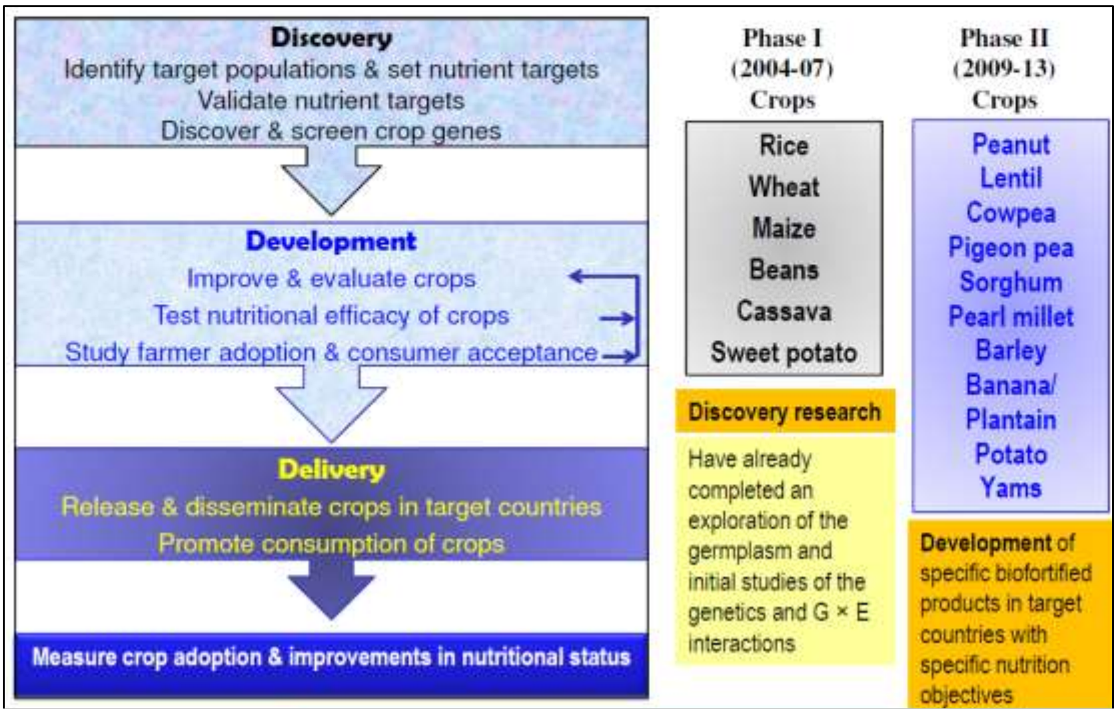
Stage 7: Nutritional Efficacy Studies on Human Subjects: Although nutrient absorption by the body is a prerequisite to preventing micronutrient deficiencies, ultimately the change in prevalence of micronutrient deficiencies with long term intake of biofortified staple foods needs to be measured directly. Thus, randomized controlled efficacy trials demonstrating the impact of biofortified crops on micronutrient status will be required to provide evidence to support the release of biofortified crops at the level of nutrient density thus far achieved (i.e., the minimum target level).

Stage 8: Release Biofortified Crops: Varietal release regulations differ by country and often by states within countries. Proof that the variety is new, distinguishable, and adds value must be established in order to register new varieties of crops. Harvest Plus works with NARES to gather the relevant information for registration and formal release of biofortified crops in target regions.

Stage 9: Facilitate Dissemination, Marketing and Consumer Acceptance: Market chain analysis, seed development and production capacity, consumer acceptance studies, and the cultivation of an enabling policy environment for the uptake and production of biofortified crops in country are essential corner stones for the development of a sustainable, independent, demand-driven, national biofortification research and implementation program.

Stage 10: Improved Nutritional Status of Target Population: Ultimately, biofortified crops are expected to improve the nutritional status of populations. Baselines and post-dissemination impact and effectiveness surveys are conducted in target regions with and without the intervention to determine whether biofortified crops can improve human health outside experimental conditions.

Harvest plus's strategy for biofortification



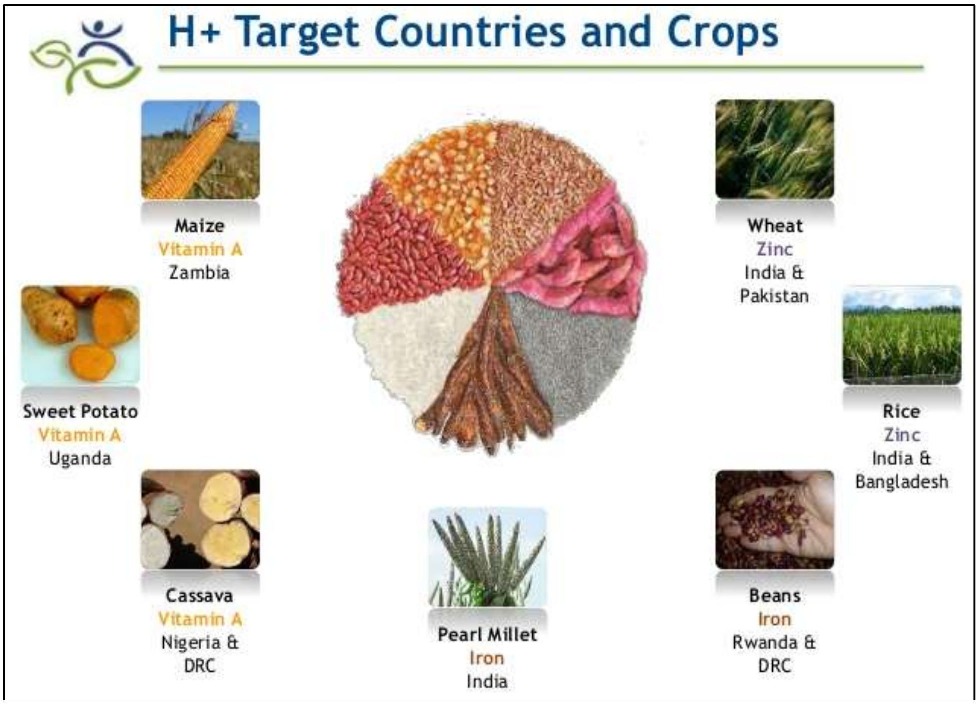


Fig 4: List of biofortified crops under HarvestPlus programme

Table 1: Crops currently undergoing bio-fortification process

Crop	Target nutrient	Nutrient range (µg/g)	Nutrient target level (µg/g)
Rice	Zinc	13-18	Polished rice
	Iron	6-24	
Wheat	Zinc	25-65	(Whole wheat)
Maize	Iron	25-56	(Whole maize)
	$\beta\beta$- Carotene	5-8.6	
	Zinc	13-58	
	Iron	10-63	
Cassava	$\beta\beta$- Carotene	0.1-20	(fresh wt.)
Beans	Iron	53-112	
	Zinc	20-55	
Sweet potato	$\beta\beta$- Carotene	0-100	(fresh wt.)
Peirl millet	Iron	47	(whole peril millet)
	Zinc	47	

Table 2: Schedule of product release after biofortification: Approved for release by National Governments after intensive multi-location testing for agronomic and micronutrient performance.

Crop	Nutrient	Countries of first release	Agronomic trait	Release year
Sweet potato	Pro-vitamin A	Uganda, Mozambique	Disease resistance, Drought tolerance, acid soil tolerance	2007
Bean	Iron, Zinc	Rwanda, DR Congo	Virus resistance, Heat and drought tolerance	2011
Pearl Millet	Iron, Zinc	India	Mildew resistance, Drought tolerance	2011
Cassava	Pro-vitamin A	Nigeria, DR Congo	Disease resistance	2014
Maize	Pro-vitamin A	Zambia	Disease resistance, Drought tolerance	2013
Rice	Zinc, Iron	Bangladesh, India	Disease and pest resistance, cold and submergence tolerance	2012
Wheat	Zinc, Iron	India, Pakistan	Disease resistance, Lodging	2013

Examples of biofortification projects include

- Iron-biofortification of rice, beans, sweet potato, cassava and legumes
- Zinc-biofortification of wheat, rice, beans, sweet potato and maize
- Provitamin A carotenoid-biofortification of sweet potato, maize and cassava
- Amino acid and protein-biofortification of sourghum and cassava

10. Case studies of bio fortification

Case study1.Rwanda's high-iron beans

In 2010, the Rwandan government introduced 4 high-iron biofortified varieties of bean. This was followed by a second wave in 2012, developed by the Rwanda Agriculture Board (RAB), the International Center for Tropical Agriculture (CIAT) and Harvest Plus. In 2012, 38% of Rwandan children under five and 17% of adult women were iron deficient. By 2014, more than 270,000 households or 15% of farmers were growing and eating the biofortified beans. These beans contain 14% more iron than commonly grown varieties. Given that Rwandans eat on average 200g of beans per day, the iron beans can provide 45% of their daily requirement of iron. HarvestPlus aims to continue to enrich their beans, with the goal of providing 60% of daily iron needs. The beans are also bred to be high yielding, virus resistant and heat tolerant. Preliminary evidence shows that consumption of iron fortified beans can increase iron status in iron-depleted Rwandan women. For example, iron-depleted female university students showed a significant increase in haemoglobin (by 3.5g/L) and total body iron (up by 0.45mg/Kg) after consuming biofortified beans for 4.5 months. Harvest Plus also released iron beans in the Democratic Republic of Congo where they are being planted by 175,000 households and in Uganda, where vitamin A enriched orange-fleshed sweet potato is already widely produced and consumed.

Case study 2. Vitamin-A Maize in Zamia

A lack of vitamin A causes blindness in 500,000 children annually and is linked to increased risk of death from disease. In Zambia, although sugar has been fortified with vitamin A since the 1990's, a 2003 National Food and Nutrition Commission showed that 54% of children under the age of 5 remained vitamin A deficient, as well as 13% of women aged 15-49.

In 2012 pre-school children in the Nyimba District of Zambia were selected to partake in a study, primarily for their willingness to participate. Children were selected who were reasonably healthy, without infection, but who had not received any vitamin A supplements in the past 6 months. Children were either fed 200g/day of white maize, the same amount of orange vitamin A fortified maize (developed by the International Maize and Wheat Improvement Centre, CIMMYT and Harvest Plus) or a vitamin A supplement. The study demonstrated that orange maize is an effective vitamin A source; those who were fed orange maize showed significant increases in their vitamin A levels. In fact, there was no statistical difference between the vitamin A levels in children who were fed the supplement and those who ate the orange maize. Harvest Plus released their first biofortified maize in 2012. By 2014, it reached 75,000 farming households, equivalent to more than 450,000 people. The maize currently provides 25% of the daily requirement of vitamin A in a typical 300g serving. However, Harvest Plus aims to provide more fortified varieties, which can provide up to 60% of the daily requirement. Emerson Banji is a Harvest Plus lead farmer in the Zambian village of Muyumbana. Despite poor rainfall in 2013, Emerson was confident that his orange maize, which is high-yielding, disease and drought-tolerant, would provide a better crop than the white maize he used to grow. He reports that 'he would prefer to always plant orange maize over white maize, because he believes it offers a better life for his family.

Case study 3. Vitamine- A Biofortified Cassava in Kenya and Nigeria

In 2011, the International Institute for Tropical Agriculture (IITA) and the National Root Crops Research Institute (NRCRI) announced the successful hybridisation and selective breeding for 3 new yellow varieties of cassava biofortified with vitamin A. Although by 2013, more than 25,000 households produced these biofortified varieties of yellow cassava, there is a long road between breeding and adoption, especially for crops that may look or taste different than local, more familiar, varieties. Improving and accelerating consumer acceptance of biofortified crops is therefore a major concern for breeders. A study carried out in the Kibwezi district of Eastern Province in Kenya tested both children between the ages of 6 and 12 and their primary care-giver (who was usually the mother, but in some cases was the father, grandparent or other adult), to establish attitudes towards switching to vitamin-A biofortified yellow-fleshed cassava. Subjects reported a significant difference in taste between the local white variety and yellow cassava. However, both groups preferred the yellow cassava because of its soft texture, sweet taste and attractive colour. Indeed, more than 70% of subjects reported a preference for the yellow cassava.

11. Major advantages of biofortification are

(i) Reaching the malnourished in rural areas

The biofortification strategy seeks to put the micronutrient-dense trait in the most profitable, highest-yielding varieties targeted to farmers and to place these traits in as many released varieties as is feasible. Moreover, marketed surplus of these crops make their way into retail outlets, reaching consumers in both rural and urban areas.

(ii) Cost-effectiveness and low cost

After one-time investment is made to develop seeds that fortify themselves, recurrent costs are low and germplasm may be shared internationally. It is this multiplier aspect of plant breeding across time and distance that makes it so cost-effective.

(iii) Behavioral change

Mineral micronutrients make up a tiny fraction of the physical mass of a seed, 5–10 parts per million in milled rice. Dense bean seeds may contain as many as 100 parts per million. Whether such small amounts will alter the appearance, taste, texture or cooking quality of foods is needed to investigate. If increased densities in iron and zinc are not noticeable by consumers, the dissemination strategy for trace minerals could rely on existing producer and consumer behavior.

(iv) Sustainability of biofortification

The biofortified crop system is highly sustainable. Nutritionally improved varieties will continue to grow and consumed year after year, even if government attention and international funding for micronutrient issue fades.

(v) Relies on the plant's biosynthetic (Vitamin) or physiological (mineral) capacity: no effect of policy change or weak funding.

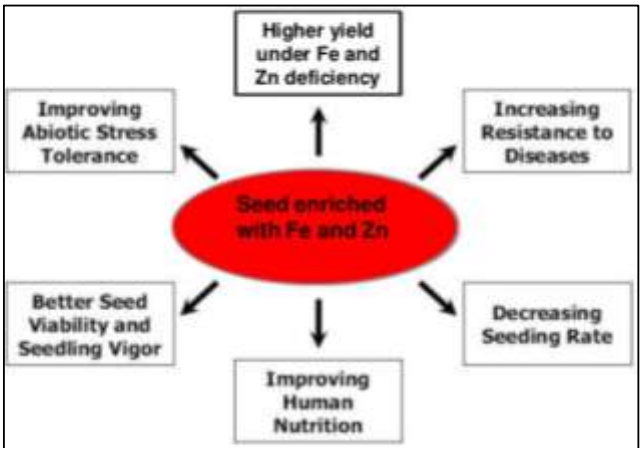


Fig 5: Benefits of biofortification in crops

12. Role of different disciplines: In biofortification interdisciplinary communication and cooperation is essential:

- Plant Breeders
- Molecular Biologists
- Food Technologists
- Human Nutritionists
- Extensionists
- Experts in Food Product Development/Marketing
- Communications
- Economists.

13. Limitations of Biofortification

(i) Low acceptability: There may occasionally be difficulties in getting biofortified foods to be accepted if they have different characteristics to their unfortified counterparts. For example, vitamin A enhanced foods are often dark yellow or orange in color – this for example is problematic for many in Africa, where white maize is eaten by humans and yellow maize is negatively associated with animal feed or food aid or where white-fleshed sweet potato is preferred to its moister, orange-fleshed counterpart

(ii) Varying impact throughout the life cycle: Biofortified staple foods can contribute to body stores of micronutrients such as iron, zinc, and vitamin A (the three target nutrients) throughout the lifecycle, including those of children, adolescents, adult women, men, and the elderly. The potential benefits from biofortification are, however, not equivalent across all of these groups and depend on the amount of staple food consumed, the prevalence of existing micronutrient deficiencies, and the micronutrient requirement as affected by daily losses of micronutrient from the body, and special needs for processes such as growth, pregnancy, and lactation.

(iii) Risk: There is a theoretical risk that a gene inserted by a genetic engineering (GE) process (such as the gene that codes for beta-carotene, the precursor of Vitamin A) could pass to related crop or wild plants with unknown effects. There is no evidence to support this risk but for this and other reasons GE crops require mandatory field-testing to assess environmental risks. These are likely to be costly and regulations in many countries may mean that a GE approach to bio fortification is only justified if using a conventional breeding technology is impossible. In general GE approaches face resistance in many countries. Marketing in the developing countries is not easy and consumer acceptance is essential for a biofortification strategy to reduce malnutrition.

14. Releases of bio fortified crops

Cumulatively, more than 150 biofortified varieties of 10 crops have been released in 30 countries. Candidate biofortified varieties across 12 crops are being evaluated for release in an additional 25 countries. Fig. 2 depicts where biofortified varieties have been tested and released to date. Biofortified crops have been released in countries indicated in dark purple, while crops are being tested in countries in light purple. This map includes countries where the International Potato Center (CIP) has worked to release the orange sweet potato. More detailed information about the varieties tested and released in each country is available on the HarvestPlus website.2

15. Future areas of investigation

Areas for further research include robust new trials that test the efficacy of biofortified crops for a wider range of age and gender groups, including infants, and over a longer time period (for example, prior to conception through infancy). Other research will test the efficacy of consuming several different biofortified crops, each providing different vitamins and/or minerals to the food basket. Nutritionists agree that biofortified crops can improve nutritional status in micronutrient-deficient populations, but additional research is needed, using other, more sensitive biochemical indicators, as well as functional indicators, to more fully understand the health impact of consuming biofortified foods.

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