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Biofortification: A promising tool to ensure nutrient-rich food production

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Abstract

Micronutrients play an important role in human growth and development. Humans depend on plant-based foods which provide no. of essential nutrients but they are deficient in key micronutrients. Micronutrient malnutrition, also known as "hidden hunger", is a serious problem in many countries, therefore micronutrient malnutrition has received serious attention in recent decades at global level. Recently, an agriculture-based approach i.e., Biofortification has been proposed as a supplementary strategy. No. of crops have been fortified through agronomic practices, conventional plant breeding, or modern biotechnology for different micronutrients and some varieties are in pipeline. Biofortification provides many benefits and it has some challenges also.

Introduction:

Micronutrients, iron (Fe), zinc (Zn), selenium (Se), iodine (I), carotenoids and folates are some of the essential nutrients for human growth and development. The majority of the world's population depends on plant-based foods which offer an array of nutrients but they are deficit in key micronutrients and do not meet the recommended daily allowances (RDA). Micronutrient malnutrition (**hidden hunger**) is a widespread public health problem in many developing countries.

Since past 40 years, the agricultural research focused on acceleration of cereal production but recently, there is a shift: "agriculture must focus not only on producing more calories to reduce hunger but also on more nutrient-rich food to reduce hidden hunger". One out of three people in the world suffers from hidden hunger, caused by a lack of minerals and vitamins in their diets. Diminishing micronutrient malnutrition has been ranked as a top priority by eminent economists and scientists at global level. There are many targeted micronutrient enhancing interventions being implemented including food supplementation, industrial fortification and nutrition education programs. Recently, an agriculture-based approach has been proposed as a supplementary strategy, namely breeding staple food crops for higher micronutrient contents. This breeding approach is termed as **biofortification**.

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Biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology (WHO). Biofortification provides a comparatively cost-effective, sustainable, and long-term means of delivering more micronutrients. Traditional agricultural approaches can marginally enhance the nutritional value of some foods whereas the advances in molecular biology are rapidly being exploited to engineer crops with enhanced key nutrients. Nutritional targets include increased mineral content, improved fatty acid composition, increased amino acid levels and enhanced antioxidant levels. Research and breeding programs are underway to enrich the major food staples in developing countries with the most important micronutrients: iron, provitamin A, zinc and folate. The adage '**health comes from the farm, not the pharmacy**' is at the heart of ongoing biofortification research and breeding programs.

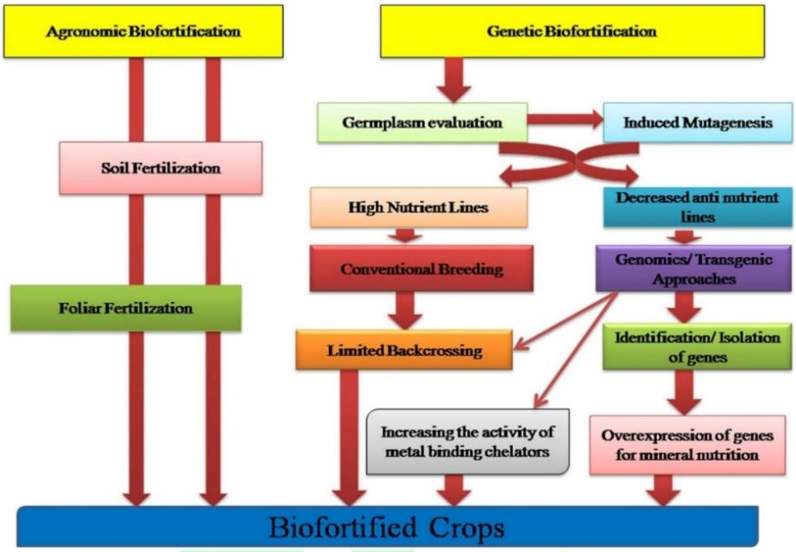
Weapons to fight malnutrition deficiencies: Dietary diversification, food supplements, food fortification and biofortification are different approaches used for improvement of the nutritional profile of crops to tackle micronutrient deficiency.

Dietary Diversification: It is a food-based strategy that involves consuming a wide range of different plant-based foods such as vegetables, fruits and whole grains. It also uses strategies at the household level, such as preparation of food that involves soaking, fermentation, and germination as these enhance micronutrient content and bioavailability.

Food Supplements: The micronutrients which are consumed in the form of pills, powders and solutions when diets alone cannot provide an adequate amount of nutrition are called food supplements. Supplementation can be used as a short-term method to improve nutritional health and may be unsustainable for large populations.

Food Fortification: Fortification simply refers to the addition of essential micronutrients including vitamins and minerals to foods for improving their nutritional quality. Several food assistance programs by the World Food Program (WFP) are running using partially pre-cooked and milled cereals and pulses fortified with micronutrients to overcome nutritional deficiencies and provide health benefits with nominal risk. E.g., for food fortification with iron- ferrous sulfate, ferrous fumarate, ferric pyrophosphate, and electrolytic iron powder compounds are commonly used.

Biofortification: Biofortification is a process of improvement of nutritional profile of plant-based foods through agronomic interventions, genetic engineering, and conventional plant breeding.



- **Agronomic Approaches**

Biofortification through agronomic approaches can be achieved by applying mineral fertilizers to the soil, foliar fertilization and soil inoculation with beneficial microorganisms.

Mineral Fertilizer: Mineral fertilizers are inorganic substances containing essential minerals and can be applied to the soil to improve the micronutrient status of soil and thus plant quality. Generally, the phyto-availability of minerals in the soil is low, therefore, to improve the concentration of minerals in the edible plant tissues, the application of mineral fertilizers with improved solubility and mobility of the minerals is required. This method can be used to fortify plants with mineral elements, but not organic nutrients, such as vitamins, which are synthesized by the plant itself.

Foliar Fertilization: Foliar fertilization is the application of fertilizers directly to the leaves. It could be successful when mineral elements are not available immediately in the soil or not readily translocated to edible tissues. Pulse crops biofortified with micronutrients, Fe, Zn, and Se, through foliar application in various studies resulted in increased levels of these micronutrients in the harvested grain.

Plant Growth Promoting Microorganisms: *Rhizobia*, mycorrhizal fungi, actinomycetes and diazotrophic bacteria are beneficial soil microorganisms associated with plant roots by symbiotic association and these protect plants by various methods such as promotion of nutrient mineralization and availability and production of plant growth hormones. Though these are naturally present in the soil, their populations can be enhanced by inoculation or agricultural management practices. Various plant growth-promoting (PGP) soil microorganisms including *Enterobacter*, *Bacillus*, and *Pseudomonas* can be exploited to increase the phyto-availability of micronutrients.

- **Genetic Engineering**

Biofortification through genetic engineering is an alternative approach when variation in the desired traits is not available naturally in the available germplasm or a specific micronutrient does not naturally exist in crops or modifications cannot be achieved by conventional breeding. Along with increasing the concentration of micronutrients, this approach can also be targeted simultaneously for removal of antinutrients or inclusion of promoters that can enhance the bioavailability of micronutrients. Several crops have been successfully modified using a transgenic approach to overcome a micronutrient deficiency. For example, enhanced accumulation (3 to 4 times) of Fe was noted in rice via expression of the iron-storage protein, ferritin.

- **Conventional plant breeding approaches**

It can benefit not only large populations but also people living in relatively remote rural areas who have limited access to commercially marketed fortified foods. This approach requires a one-time investment in plant breeding and can be grown and multiplied across years by farmers at virtually zero marginal cost. Genetic diversity is required in the gene pool to achieve success in biofortification through the plant breeding approach.

CROP	NUTRIENT	TARGET COUNTRY	LEAD INSTITUTIONS	FIRST RELEASE YEAR
Banana/Plantain	Provitamin A Carotenoids	Nigeria, Ivory Coast, Cameroon, Burundi, DR Congo	IITA, Bioversity	Unknown
	Provitamin A Carotenoids, Iron*	Uganda	Queensland University of Technology, NARO	2019
Bean	Iron (Zinc)	Rwanda, DR Congo Brazil	CIAT, RAB, INERA Embrapa	2012 2008
Cassava	Provitamin A Carotenoids	DR Congo Nigeria Brazil	IITA, CIAT, INERA IITA, CIAT, NRCRI Embrapa	2008 2011 2009
	Provitamin A Carotenoids, Iron*	Nigeria, Kenya	Donald Danforth Plant Science Center	2017
Cowpea	Iron, Zinc	India Brazil	G.B. Pant University Embrapa	2008 2008
Irish potato	Iron	Rwanda, Ethiopia	CIP	Unknown
Lentil	Iron, Zinc	Nepal, Bangladesh, Ethiopia, India, Syria	ICARDA	2012
Maize	Provitamin A Carotenoids	Zambia Nigeria Brazil China India	CIMMYT, IITA, ZARI CIMMYT, IITA, IAR&T Embrapa Institute of Crop Science, YAAS DBT	2012 2012 2013 2015 Unknown
Pearl millet	Iron (Zinc)	India	ICRISAT	2012
Pumpkin	Provitamin A Carotenoids	Brazil	Embrapa	2015

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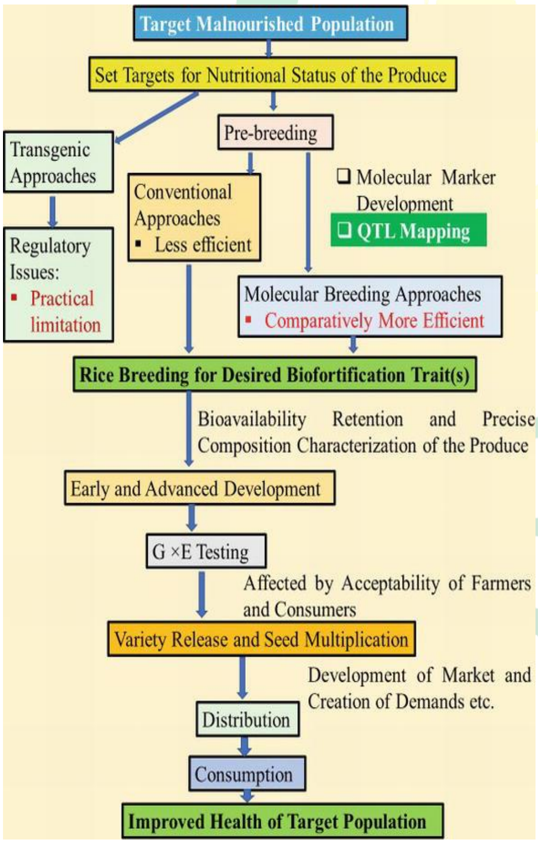
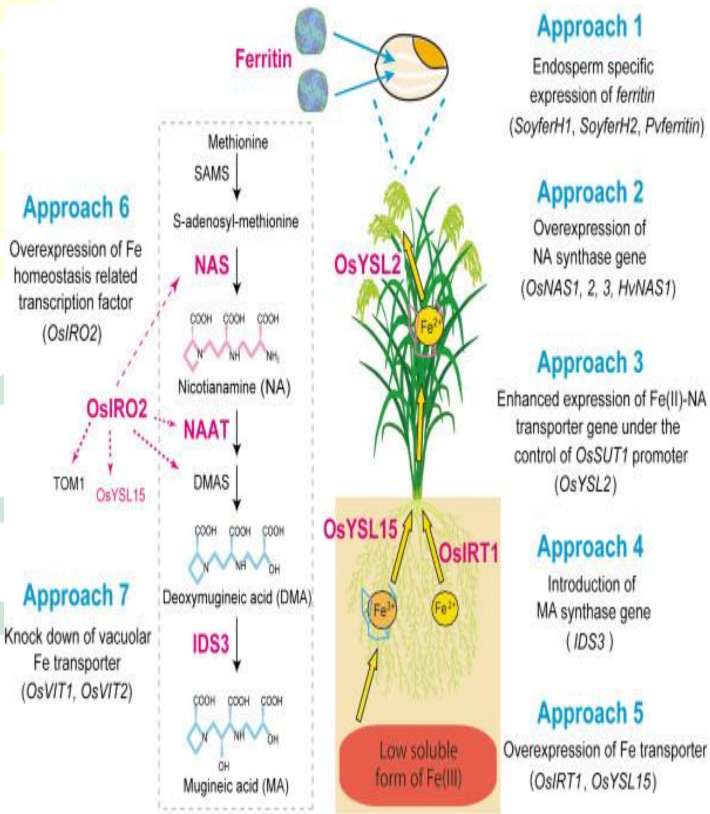
Rice	Zinc (Iron)	Bangladesh, India Brazil	IRRI, BRRI Embrapa
	Provitamin A Carotenoids*	Philippines, Bangladesh, Indonesia, India	Golden Rice Network,
	Iron*	Bangladesh, India	University of Melbourne
	Iron	China	Institute of Crop Scie CAAS
Sorghum	Zinc, Iron	India	ICRISAT
	Provitamin A Carotenoids*	Kenya, Burkina Faso, Nigeria	Africa Harvest, Pionee Bred
Sweet potato	Provitamin A Carotenoids	Uganda Mozambique Brazil China	CIP, NaCCRI CIP Embrapa Institute of Sweet Pot CAAS
Wheat	Zinc (Iron)	India, Pakistan	CIMMYT
	Zinc (Iron)	China	Institute of Crop Scie CAAS
	Zinc (Iron)	Brazil	Embrapa

Pathway for Biofortification



Different transgenic approaches for Fe Biofortification in Rice



Benefits of biofortification: According to many researchers, hidden hunger can be solved by biofortifying food crops.

- Biofortification helps in achieving overall health improvement in the people.
- Biofortified crops are more resilient to diseases, pests, droughts, etc. and provide better yields.
- It offers a food-based, sustainable and low-dose alternative to iron supplements.
- It has the potential to reach the poorest section of society (who cannot afford food supplements) and will also benefit farmers.
- It is highly cost-effective since once the initial research is done, the process can be easily replicated and scaled.
- Biofortification done through non-genetically modified methods (like traditional plant breeding done in India) is a better alternative then introducing GM crops that face implementation barriers.
- In a country such as India, that faces huge nutritional challenges, biofortification is a sustainable, cost-effective method that can help resolve this challenge.

Biofortification Challenges

- Due to the colour changes in the grain, people hesitate to accept biofortified food as in the case of golden rice.
- The initial costs also can be a barrier for people to implement.

Conclusions

Micronutrients are essential for human growth and development and their deficiency is a major concern that affects one in three people worldwide. Among various strategies, biofortification through plant breeding is considered the most economical and sustainable approach to tackle micronutrient deficiencies. This approach is universally accepted and has the potential to reach people living in relatively remote rural areas that have limited access to commercially marketed fortified foods. In recent years, significant progress has been made with the release of several biofortified crop varieties that are helping to overcome micronutrient deficiencies in the target populations.

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