Review Paper

Apromising approach for addressing micronutrient deficiencies and enhancing nutritional quality in food crops through Biofortification

Abstract

Biofortification is a promising agricultural approach for addressing micronutrient shortages and increasing the nutritional content of food crops. Micronutrient deficiencies, also known as "hidden hunger," continue to affect many people around the world, particularly in underdeveloped countries. This presentation emphasises the need of biofortification in solving this worldwide health issue. Biofortification tries to improve the level of important micronutrients such as iron, zinc, vitamin A, and iodine in edible plant portions by using traditional breeding techniques or current biotechnological procedures. Iron-fortified beans, zinc-enhanced rice, vitamin A-rich sweet potatoes, and iodine-enriched crops are all examples of successful biofortified crops. To maximise their impact, biofortification programmes must be integrated with nutrition education and agronomic practises, according to the abstract. Governments, research institutes, non-governmental organisations, and the commercial sector must work together to scale up biofortification activities and build healthier, more resilient communities around the world.

Introduction

Crop biofortification refers to the technique of enriching plant seeds with nutritionally significant chemicals. Modern agriculture has been mainly successful in supplying the energy needs of developing-country disadvantaged populations. Over the last 40 years, agricultural research has prioritised greater cereal production. A recent transition has occurred: agriculture must now provide not just more calories to lessen hunger, but also more nutrient-rich food to minimise hidden hunger. One in every three persons worldwide suffers from hidden hunger, which is caused by a lack of minerals and vitamins in their diets and has serious health repercussions.(Bangarayya*et al.* 2016).The biofortification strategy aims to introduce the micronutrient-dense trait into varieties that already have desirable agronomic and consumer characteristics, such as high yield. In contrast to complementing efforts, such as fortification and supplementation, which begin in urban settings, market surpluses of these crops may make their way into retail outlets, reaching customers in rural and then urban regions. Although biofortified staple foods cannot provide as many minerals and vitamins per day as supplements or industrially fortified meals, they can aid by boosting the daily adequacy of micronutrient intakes among individuals throughout the life cycle(Velu et al., 2011).

In order of prevalence, the most widely recognised micronutrient deficiencies across all ages are caused by a deficiency of iodine, Fe, or Zn. Vitamin A deficiency is less frequent but still significant in terms of public health, affecting an estimated 190 million preschool children and 19 million pregnant women. Other critical micronutrients, such as calcium, vitamin D, and B vitamins like folate, are also commonly deficient. Hidden hunger disproportionately affects pregnant women and children, impairing their health throughout their lives and increasing mortality rates owing to nutritional deficiencies. Malnutrition is one of the leading causes of death worldwide, killing over 20 million people each year (WHO, 2007). Malnutrition is also a major contributor to rising sickness, disability, and stunted mental and physical growth (WHO and FAO, 2002). To meet micronutrient and energy requirements, a suitable diet of fruits, vegetables, and animal products is essential. However, these products are out of reach for the vast majority of the world's population. While practically all plants are capable of synthesising and accumulating micronutrients, the edible sections of several staple crop plants are deficient in micronutrients such as iron (Fe), zinc (Zn), vitamin A, folate, and so on.

2.1 Types of Biofortification:

2.1.1 Conventional breeding approaches: Traditional breeding techniques entail selecting and crossbreeding crop types with desirable features in order to generate new kinds with higher nutritional value. This approach is based on the natural genetic variety found in plant species. Breeders choose parent plants with higher amounts of certain micronutrients and cross them to produce offspring with better nutritional profiles. The offspring are then assessed and selected based on their micronutrient content, resulting in the development of biofortified crop types. Conventional breeding is a tried-and-true strategy for biofortification that has less regulatory hurdles than genetic engineering techniques(Thyagarajan*et al.*, 2003).

2.1.2 Genetic engineering techniques: The direct alteration of an organism's DNA to introduce or enhance specified traits is known as genetic engineering, often known as biotechnology. Genetic engineering techniques can be employed in the context of biofortification to introduce genes responsible for the synthesis or accumulation of important micronutrients into food crops. Scientists can, for example, insert genes coding for iron or vitamin A production from other sources into crop plants, producing in increased quantities of these micronutrients in the plant's edible sections. Although genetic engineering allows for more exact control over desirable features, it may face harsher regulatory scrutiny and societal acceptance difficulties(Trivedi*et al.*, 2011).

2.1.3 Agronomic practices for biofortification: Agronomic practises influence the availability and uptake of micronutrients in crops, which is critical for biofortification. Certain agricultural practises can boost the nutritional content of crops cultivated in nutrient-deficient soils. Adding micronutrient-rich fertilisers, such as zinc or iodine, for example, can improve the nutritional content of harvested crops. Soil management practises like liming and pH control can also affect the bioavailability of key minerals for plant uptake. Furthermore, improving irrigation and water management practises can have an impact on nutrient absorption and movement within the plant. Agronomic biofortification supplements other biofortification technologies and can be especially beneficial in areas where conventional breeding or genetic engineering may be limited(Srivastav*et al.*, 2016).

3. Biofortification of key micronutrients:

3.1 Iron (Fe) Biofortification: Iron deficiency is one of the most widespread micronutrient deficiencies globally, leading to anemia and impaired cognitive development. Biofortification of staple food crops, such as rice, wheat, beans, and pearl millet, aims to increase the iron content in their edible parts (Mishra*et al.,* 2018). Conventional breeding approaches have been successful in developing iron-rich varieties, and genetic engineering techniques have shown promise in increasing iron accumulation by enhancing iron transport and storage within the plant(Ramesh *et al.,* 2016).

Table 1: Effect of Zn, Fe, Mo and *Rhizobium* biofortification on grain yield and proteincontentofchickpea

Treatments	**Seed yield(q/ha)**	**Responseovercontrol(%)**	**Proteincontentingrain(%)**
Control	**10.00**	**_**	**19.31**
R1+Fe	**12.60**	**26.0**	**20.62**
R1+Mo	**13.60**	**36.0**	**21.37**
R1+Zn	**12.90**	**29.0**	**20.56**
R1+Fe+Mo	**17.80**	**78.0**	**21.75**
R1+Fe+Zn	**17.20**	**72.0**	**21.12**
R1+Zn+Mo	**16.90**	**69.0**	**20.93**
R1+Fe+Mo+Zn	**19.45**	**94.5**	**23.00**
R1:with *Rhizobium*			

Periyar*et al*. (2016) revealed that seed treatment with *Rhizobium* + Zn + Fe + Mo in chickpea (microorganism + micro nutrient biofortification) recorded higher seed yield (19.45 q ha^{-1}) and proteincontentin grain (23 %) compared to other treatments.

Kushawaha*et al*., 1997 reported that application of iron (5.6 kg ha^{-1}) resulted grain, root and shoot iron content 4.6 mg, 3.16 mg and 1.7 mg in 100 g chickpea seed respectively. According to Salih foliar fertilization of 2 ppm Fe and 2 ppm Zn reported maximum increase in Fe (154 mg kg^{-1}) and Zn (42 mg kg^{-1}) content of cowpea seed respectively. Nandan *et al.*pointed out that foliar spray of 0.05 per cent Fe along with recommended dose of fertilizer resulted significantly higher iron content in seed (66.46 mg kg^{-1}) and stover (66.83 mg kg^{-1}).

3.2 Zinc (Zn) Biofortification: Zinc deficiency affects millions of people, leading to compromised immune function and growth retardation. Biofortification of crops like wheat, rice, maize, and beans targets increasing zinc concentrations in their edible parts. Conventional breeding methods have been utilized to develop high-zinc varieties, and genetic engineering approaches have also been explored to enhance zinc uptake and transport within plants(Yamunarani*et al,* 2015).

Table 2: Effect of micronutrients biofortification on growth, yield and yield attributes of frenchbean (pooled data of two years)

Treatments (kgha^{-1})	**Plant height(cm)**	**Podlength(cm)**	**Pods Plant^{-1}**	**100-seedweight(g)**	**Grain yield (kgha)$^{-1}$**	**Straw yield (kgha)$^{-1}$**	**Protein (kgha)$^{-1}$**
T$_1$:Control	51.40	12.81	6.66	51.13	1901	2136	498.54
T$_2$:Zn @3kg	54.31	13.44	8.25	53.79	2143	2452	578.19
T$_3$:Zn @6kg	**60.01**	**15.47**	**12.02**	**55.94**	**2515**	**2802**	**686.42**
T$_4$:Mo@0.5kg	55.47	13.59	8.72	54.20	2209	2522	602.43
T$_5$:Mo @ 1kg	**59.29**	**14.14**	**10.43**	**55.15**	**2478**	**2706**	**668.38**
T$_6$: B @ 0.5kg	**63.05**	**18.68**	**15.04**	**58.60**	**2769**	**2943**	**706.71**
T$_7$: B @ 1kg	51.45	12.93	7.94	53.05	1977	2268	529.24
CDat 0.05	2.67	0.57	0.43	1.48	174	224	38.98

Rajesh *et al*. (2016) reported that application of boron (0.5 kg ha^{-1}) on french bean recorded significantly higher plant height (63.05 cm), pod length (18.68 cm), 100 seed weight (58.60 g), grain yield (2769 kg ha^{-1}), straw yield (2943 kg ha^{-1}) and protein (706.71 kg ha^{-1}) compared to other treatments.

3.3 Vitamin A Biofortification: Vitamin A insufficiency is a major public health concern since it impairs vision and increases susceptibility to infections. Biofortification aims to increase the provitamin A carotenoid content of crops such as sweet potatoes, maize, and cassava, which can then be transformed into active vitamin A in the human body(Paine*et al.*, 2005). Conventional breeding has yielded vitamin A-rich crop varieties, and genetic engineering approaches have been used to boost carotenoid biosynthesis(Rai *et al.*, 2004).

3.4 Iodine (I) Biofortification: Iodine shortage can result in thyroid diseases and decreased cognitive development, especially in areas with low soil iodine levels. Biofortification of crops like rice and potatoes entails enhancing iodine uptake and accumulation in edible plant portions. To alleviate iodine shortage in afflicted areas, agronomic practises such as employing iodine-enriched fertilisers or iodine-fortified irrigation water have been used(Rajesh *et al.*, 2016).

3.5 Other Biofortification Targets: Beyond the key micronutrients mentioned above, biofortification research is exploring ways to enhance the content of other essential vitamins and minerals in food crops. For instance, biofortification efforts aim to increase the content of folate (vitamin B9) in crops like rice and wheat, which is essential for proper fetal development and overall health. Additionally, efforts are underway to biofortify crops with essential minerals such as selenium and calcium, which play vital roles in various physiological processes(Shekhawar*et al.*, 2018).

4. Biofortification Techniques and Strategies

4.1 Marker-assisted selection (MAS): Marker-assisted selection (MAS) is a biofortification technique that leverages genetic markers to identify and select crop plants with desired traits, such as higher levels of specific micronutrients. Through the analysis of genetic markers closely linked to target genes responsible for nutrient accumulation, plant breeders can efficiently screen large populations of plants and identify those carrying the desired traits. MAS expedites the breeding process, allowing the development of biofortified crop varieties with improved nutritional content. This technique is particularly useful for breeding programs aiming to enhance micronutrient levels without introducing genes from other species (Velu*et al.*, 2011).

Hittalamani, S., *et al.*, 2014 released three biofortified rice varities (Paustic-1, 7 and 9) it is an improved high yielding variety, suitable for *Kharif* and summer cultivation under tank, well and canal irrigation. This variety is resistant to green leaf hopper and moderately resistant to stem borer, bacterial leaf blight and susceptible to brown plant hoppers, gall midge and tungro virus. It yields about 40 quintals per hectare in *Kharif* and 50-60 quintals per hectare in summer.

Yamunarani*et al.*, 2015 reported biofortified ragi varities through different genetical and agronomical methods Biofortification in ragi is still limited by the presence of antinutrients like phytic acid, polyphenols, and tannins. RNA interference and genome editing tools [zinc finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs), and clustered regularly interspaced short palindromic repeats (CRISPR)] needs to be employed to reduce these antinutrients.

4.2 Transgenic approaches: Transgenic approaches in biofortification involve the genetic engineering of crops to introduce specific genes responsible for the synthesis or accumulation of essential micronutrients. Scientists isolate genes from other organisms that produce higher levels of the desired micronutrients and insert them into the genome of target crop plants. This modification enables the crop to produce increased amounts of specific vitamins or minerals, such as provitamin A or iron. Transgenic biofortification offers precise control over the nutrient content of crops, but it may face regulatory and public acceptance challenges related to genetically modified organisms (GMOs) (Paine*et al.*, 2005).

4.3 **Zinc fertilization techniques:** Zinc fertilization is an agronomic biofortification strategy that focuses on increasing the zinc content of crops by applying zinc-rich fertilizers to the soil or as foliar sprays(Raghu *et al.*, 2015). Zinc is a vital micronutrient for both plant growth and human health, and its deficiency can lead to impaired development and health issues in humans. By providing crops with sufficient zinc through fertilization, farmers can improve the nutritional quality of the harvested produce, especially in regions with zinc-deficient soils (Cakmak*et al.*,1999).

4.4 Foliar and seed coating applications: Foliar and seed coating applications are practical biofortification techniques that involve directly applying micronutrient solutions to the leaves (foliar) or coating seeds (seed coating) with essential nutrients(Periyar*et al.,* 2016). In foliar application, crops are sprayed with nutrient solutions during specific growth stages, and the nutrients are absorbed through the leaves. Seed coating, on the other hand, involves coating the seeds with a layer of micronutrients before planting. As the seeds germinate, the nutrients from the coating are taken up by the emerging seedlings. These techniques provide a rapid and efficient way to supplement crops with essential micronutrients, especially in areas with nutrient-deficient soils (Impa*et al.,* 2013).

4.5 Biofortification through plant-associated microbes: Biofortification through plant-associated microbes involves harnessing beneficial microorganisms that interact with plants to enhance nutrient uptake and assimilation. These microbes, such as certain rhizobacteria or mycorrhizal fungi, can facilitate the solubilization and mobilization of nutrients in the soil, making them more available for plant uptake. By forming symbiotic relationships with plants, these microbes contribute to improved nutrient acquisition and can lead to enhanced nutrient content in the harvested crops. Biofortification through plant-associated microbes offers a sustainable and environmentally friendly approach to improve crop nutrition (Khan*et al.,* 2009).

Kumaraswamy and Rajasekaran (2014) reported that application of *Azospirillum* + *Phosphobacteria*recorded higher cane yield (122.7 t ha^{-1}) and sugar yield (14.9 t ha^{-1}) Azospirillum in conferring to plants tolerance of abiotic and biotic stresses, which may be mediated by phytohormones acting as signaling molecules. Tolerance of biotic stresses is controlled by mechanisms of induced systemic resistance, mediated by increased levels of phytohormones in the jasmonic acid/ethylene pathway, independent of salicylic acid (SA), whereas in the systemic acquired resistance mechanism previously studied with phytopathogens it is controlled by intermediate levels of SA. Both mechanisms are related to the NPR1 protein, acting as a co-activator in the induction of defense genes. Azospirillum can also promote plant growth by mechanisms of tolerance of abiotic stresses, named as induced systemic tolerance.

5. Biofortified crops with agronomic traits

1. **Biofortified Rice:**
    - High Iron Rice: Developed to address iron deficiency, these rice varieties have enhanced iron content in their grains.
    - Submergence-Tolerant Rice: These rice varieties are engineered to withstand flooding and submergence, making them suitable for flood-prone areas.
2. **Biofortified Maize:**
    - Provitamin A (Beta-carotene) Maize: These maize varieties have increased levels of provitamin A, which can be converted to vitamin A in the body, addressing vitamin A deficiency.
    - Drought-Tolerant Maize: Developed to withstand drought conditions, these maize varieties ensure better yield in water-stressed regions.
3. **Biofortified Wheat:**

- High Zinc Wheat: These wheat varieties are enriched with zinc, addressing zinc deficiency in populations consuming wheat as a staple food.
- Disease-Resistant Wheat: Some biofortified wheat varieties are developed with enhanced disease resistance to protect against common wheat pathogens.

4. **Biofortified Pearl Millet:**
    - High Iron Pearl Millet: These varieties have increased iron content, combating iron deficiency and improving overall nutritional value.
    - Heat-Tolerant Pearl Millet: Developed to tolerate high temperatures, these varieties can thrive in hot and arid regions.
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5. **Biofortified Sweet Potato:**
    - Provitamin A (Beta-carotene) Sweet Potato: These sweet potato varieties are rich in provitamin A, promoting vitamin A sufficiency in diets.
    - Soil-Adaptable Sweet Potato: Developed to grow well in different soil types, these varieties can be cultivated in diverse agricultural environments.

Table 3: Biofortified crops with agronomic traits

Crop	**Nutrient**	**Agronomictrait**
Sweetpotato	ProvitaminA	Diseaseresistance,droughttolerance
Bean	Iron,zinc	Virusresistance,heatanddroughttolerance
Pearlmillet	Iron,zinc	Mildewresistance,droughttolerance
Cassava	ProvitaminA	Diseaseresistance
Maize	ProvitaminA	Diseaseresistance,droughttolerance
Rice	Zinc,iron	Disease&pestresistance,cold&submergencetolerance
Wheat	Zinc,iron	Diseaseandlodgingresistance

6. Recentlyreleased biofortifiedcropsin India

Fig 1: Recentlyreleased biofortifiedcropsin India

To alleviate the country's malnutrition problem, India has recently created 17 biofortified variants of eight crops. On the occasion of the Agriculture and Food Organization's 75th anniversary, India's Prime Minister, Narendra Modi, dedicated these biofortified varieties to the nation. Rice, wheat, maize, pearl millet, sorghum, chickpea, pigeon pea, and small millet are the eight crops that have been created as biofortified versions. These biofortified variants offer up to three times the nutritious value of non-biofortified equivalents.

Conclusion

Biofortification emerges as a potential and successful technique for combating micronutrient shortages and improving food crop nutritional quality. Biofortification provides a versatile and sustainable solution to hidden hunger and malnutrition through a variety of techniques such as marker-assisted selection (MAS), transgenic approaches, zinc fertilisation techniques, foliar and seed coating applications, and the use of plant-associated microbes. We can help poor populations gain access to important micronutrients, enhance overall health outcomes, and promote global food security by incorporating biofortified crop types into agricultural systems. Continued research, investment, and collaboration across governments, research institutions, and communities are critical to realising biofortification's full potential and guaranteeing a healthier and more resilient future for global nutrition.

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