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Biofortification: An Ideal Approach for Nutritional Upliftment

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Abstract

Biofortification refers to the enhancement of the nutrient profile of staple crops through methods such as traditional breeding, improved agronomic practices, and modern biotechnological tools. The process is designed in a way that preserves the desirable traits valued by both farmers and consumers. It is considered a nutrition-sensitive agricultural intervention aimed at lowering the prevalence of micronutrient deficiencies. Current research and implementation efforts include the enrichment of cassava, maize, rice, and sweet potato with pro-vitamin A carotenoids; maize, rice, and wheat with zinc; and beans, cowpea, and pearl millet with iron.

Globally, more than half of the population experiences inadequate intake of vital micronutrients such as iron, zinc, and essential vitamins. While supplementation and industrial fortification have been beneficial in addressing these deficiencies, additional strategies are required, especially for underserved populations in remote rural regions. Biofortification provides an effective solution by not only increasing the nutritional value of crops but also contributing to better yields and agricultural sustainability. In low- and middle-income countries, integrating higher levels of nutrients directly into staple crops ensures a more sustainable supply of essential micronutrients.

Evidence from feasibility and impact studies, along with progress in dissemination approaches, demonstrates that biofortification has strong potential as a long-term response to hidden hunger.

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Introduction

Biofortification refers to the development of staple crops enriched with vital micronutrients through the integration of advanced biotechnological tools and improved traditional breeding methods. This approach primarily targets crop such as rice, wheat, maize, and millets. Its main objective is to reduce mortality and illness linked to micronutrient malnutrition while simultaneously enhancing food security, agricultural productivity, and overall quality of life in disadvantaged communities of developing nations. By producing staple crops that deliver higher levels of bioavailable nutrients in a sustainable and cost-effective way, biofortification serves as a long-term nutritional intervention.

The term hidden hunger describes a condition in which individuals consume sufficient calories to meet their energy needs, yet their diets lack essential vitamins and minerals crucial for both mental and physical health. This condition is especially harmful to children and adolescents, as it can impair cognitive and physical development, result in blindness, stunted growth, and reduced intellectual capacity. Women and young children are particularly vulnerable. Moreover, hidden hunger undermines adult productivity by increasing susceptibility to illness and decreasing work capacity. Globally, around two billion people are estimated to be affected by this problem. The most critical nutrients associated with hidden hunger are zinc (Zn), iron (Fe), and vitamin A.

In areas where access to diverse diets and conventional micronutrient interventions is limited, biofortification emerges as a promising, affordable, and durable means of improving nutrient intake. However, the staple crops widely consumed worldwide generally fall short in providing adequate micronutrient levels for optimal human growth and development.

Several measures exist to address these deficiencies, such as dietary diversification, nutrient supplementation, industrial food fortification, and crop biofortification. Of these, crop biofortification stands out as the most practical, long-lasting, and widely acceptable approach to counter the global challenge of hidden hunger. The potato, for instance, already contains a variety of nutrients, particularly when eaten with its skin. Enhancing its nutrient profile through biofortification could significantly benefit populations at risk of micronutrient deficiencies.

This review discusses the major facets of crop biofortification, including conventional plant breeding, agronomic practices, and genetic engineering. Evidence from multiple studies indicates that enriching staple crops with vital nutrients is an effective strategy to reduce micronutrient malnutrition and tackle hidden hunger. Owing to its affordability and sustainability, biofortification is advantageous for both individuals and governments. Additionally, it complements other nutrition-related initiatives such as supplementation and food fortification. Importantly, biofortification provides an effective solution for populations unable to modify their eating patterns due to financial, cultural, geographical, or religious limitations.

Conventional Breeding Technique

Traditional plant breeding, when combined with advanced phenotyping tools and modern biotechnological approaches, makes it possible to improve the micronutrient concentration of newly developed crop varieties. The naturally occurring genetic diversity in plants provides opportunities for enhancing essential vitamin and mineral levels through breeding strategies [1,2]. Historically, conventional breeding has primarily focused on maximizing yield potential by exploiting heterosis for higher grain production and by developing resistance genes against diverse pests and pathogens in cross-pollinated species.

For example, the study "Conventional and Molecular Breeding Approaches for Biofortification of Pearl Millet" highlights significant progress in breeding pearl millet lines rich in iron, with collaborations involving both public and private organizations such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the National Agricultural Research System (NARS) [3]. Success in such programs is possible only when biofortified lines not only retain high productivity but also ensure superior nutrient density, benefiting both producers and consumers. Interestingly, the micronutrient levels in pearl millet have been observed to remain relatively more stable than yield and yield-related traits, similar to other cereals [4,5].

Agronomic Biofortification Technique

Agronomic biofortification involves enriching soils or plants with micronutrient-containing fertilizers to improve the nutritional profile of edible plant parts. This approach, often described as simple and rapid, can significantly increase crop nutrient value, which in turn enhances human dietary intake [6]. Major strategies include fertilizer supplementation, solubilization of minerals, and efficient translocation of elements from source tissues to edible sinks. While macronutrients like nitrogen (N), phosphorus (P), and potassium (K) primarily drive yield goals, micronutrients address hidden hunger.

Practical success of this technique has been evident in different countries—selenium fertilization in Finland, zinc enrichment in Turkey, and iodine application in China [7-9]. In mustard, for instance, selenium uptake has been enhanced through rhizospheric microorganisms and bioformulations [10]. Likewise, foliar sprays of zinc significantly raised Zn content in potato tubers, with ZnO and $ZnSO_4$ proving more effective than $ZnNO_3$ in improving nutritional levels without compromising yield [11].

Recent research on the use of fertilizers—whether conventional, biofertilizers, or nanofertilizers—emphasizes their potential to fortify staple and non-staple crops with key micronutrients like Zn, Fe, and Se. However, the efficiency of agronomic biofortification depends on various factors, including type and dosage of fertilizers, crop species, and soil conditions, and many knowledge gaps still remain.

Transgenic Biofortification

Genetic engineering offers opportunities to develop new plant varieties with targeted nutritional enhancements by introducing and expressing genes across species barriers. This method draws from an unlimited gene pool, enabling the transfer of traits between distantly related organisms. Transgenic approaches remain the most feasible option when a crop lacks the genetic capacity to synthesize or accumulate a required nutrient.

The success of transgenic biofortification depends heavily on identifying, characterizing, and manipulating genes that regulate metabolic pathways. By doing so, crops can be tailored to produce or accumulate essential vitamins and minerals not naturally present in sufficient amounts. In many cases, these biotechnological interventions provide the only reliable pathway for addressing micronutrient deficiencies in specific food crops.

Genetic Engineering and Transgenic Crops for Nutritional Improvement

Several molecular strategies have been employed to develop transgenic crops enriched with essential nutrients. These strategies include the introduction of novel genes, overexpression of native genes, silencing or down-regulation of specific genes, and disruption of pathways that produce inhibitors of nutrient accumulation. Genetic interventions can also redistribute micronutrients between plant tissues, enhance their concentration in edible portions, strengthen existing metabolic pathways, or reconstruct entire biosynthetic routes to increase nutritional value.

Unlike conventional biofortification programs based on dietary guidance or agronomic inputs, transgenic approaches require substantial time, investment, and advanced research in the early stages. However, once developed, these crops offer a cost-effective and sustainable solution to combating malnutrition [12,13]. Importantly, genetic engineering is not restricted by taxonomic boundaries—synthetic or modified genes can be created and introduced into target crops. Such advancements could play a pivotal role in addressing micronutrient deficiencies, particularly among marginalized populations in low- and middle-income countries [14].

Micronutrient Malnutrition: A Global Burden

Micronutrient malnutrition (MNM) arises from insufficient intake of essential vitamins and minerals required in trace amounts for growth, immunity, and development. Deficiencies in micronutrients such as iron, zinc, calcium, iodine, vitamin A, B-complex vitamins, and vitamin C remain one of the most pressing global health challenges. They impair physical growth, weaken immunity, increase susceptibility to infections, and in severe cases, lead to irreversible outcomes such as blindness, stunting, and cognitive impairment [15].

The problem disproportionately affects pregnant women and children under five years of age, where deficiencies manifest as stunting, wasting, and underweight conditions. According to UNICEF (2012), nearly 6.9 million children under five died globally in 2011, with malnutrition being a major contributing factor [16]. An estimated 165 million children were stunted, 101 million underweight, and 52 million wasted, with the majority residing in South Asia and sub-Saharan Africa. India alone accounts for more than one-third of the world's stunted children [17].

Micronutrients also play crucial roles in immune modulation. For instance, vitamin A, zinc, selenium, and folate influence cellular signaling, pathogen resistance, and oxidative stress regulation. Deficiencies not only heighten infection risk but can also worsen the severity of diseases or hinder recovery. Moreover, since most nutrients originate from agriculture-based food systems, micronutrient security is directly linked to agricultural practices and crop nutrient quality.

Biofortification as a Strategy against Hidden Hunger

In regions where staple cereals such as rice, wheat, and maize dominate diets, and where dietary diversification or supplementation programs remain inadequate, the prevalence of micronutrient deficiencies is especially high. The consequences—reduced cognitive capacity, impaired productivity, and increased vulnerability to infections—translate into long-term public health and economic burdens, often referred to as "hidden hunger".

Given limited arable land and the pressure of a growing global population, there is an urgent need for nutrient-enriched staple crops. Biofortification offers a sustainable solution by enhancing the nutrient density of crops through conventional breeding, agronomic approaches, or advanced genetic engineering. Programs such as HarvestPlus have already demonstrated success by targeting crops rich in iron, zinc, and vitamin A, the three micronutrients most widely recognized by the World Health Organization as being deficient in global diets.

Biofortification also has indirect benefits—improving livestock fodder quality, reducing reliance on chemical supplementation, and contributing to overall food system resilience. However, the success of biofortification depends on both crop and soil factors. In certain cases, combining genetic approaches with micronutrient fertilization may be required to ensure both crop productivity and nutrient density in edible tissues [1].

Hidden hunger continues to undermine the health and development of millions, particularly in low-income countries where diets are dominated by monotonous staples. Biofortification—through conventional, agronomic, or transgenic methods—offers a sustainable, long-term solution. By improving the nutrient content of widely consumed crops, it reduces the reliance on costly supplementation programs and directly addresses deficiencies in vulnerable populations. Coupled with soil fertility management and supportive policies, biofortification can play a transformative role in combating malnutrition and promoting global food and nutrition security.

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Conclusion

Hidden hunger, also referred to as micronutrient malnutrition, remains a silent barrier to health and development across the globe. It is particularly widespread in low- and middle-income countries where diets are predominantly based on staple foods such as rice, wheat, or maize. These foods provide energy but lack sufficient amounts of essential vitamins and minerals, leading to long-term nutritional deficiencies that compromise immunity, cognitive ability, and productivity.

Biofortification has emerged as a promising and sustainable strategy to address this challenge. Unlike short-term interventions such as supplementation or industrial fortification, biofortification enhances the nutrient density of food crops themselves, ensuring that populations receive improved nutrition through their daily diets. This approach can be achieved through conventional plant breeding, agronomic practices like micronutrient fertilization, or modern transgenic methods. For example, crops enriched with iron, zinc, or provitamin A directly contribute to reducing deficiencies among vulnerable groups, especially women and children [18-38].

The success of biofortification, however, also depends on complementary measures such as improving soil fertility, adopting farmer-friendly practices, and ensuring that supportive government policies promote both production and consumption of nutrient-enriched varieties. When effectively integrated into agricultural systems, biofortified crops can reduce dependency on costly supplementation programs, enhance resilience against malnutrition, and contribute significantly to food and nutrition security on a global scale. Ultimately, biofortification represents a cost-effective and farmer-centered approach that strengthens both public health and agricultural sustainability, offering long-term benefits for populations at risk of hidden hunger.

References

1. Cakmak I (2008) Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil 302: 1-17.
2. MonasterioI,GrahamRD(2000)Breedingfortrace minerals in wheat. Food Nutr Bull 21: 392-396.
3. Govindaraj M, Yadav OP, Srivastava RK, Gupta SK (2019) Conventional and molecular breeding approaches for biofortification of pearl millet. Quality breeding in field crops 85-107.
4. Satyavathi CT, Sankar SM, Singh SP, Bhowmick P, Bhat J, et al. (2015) Stability analysis of grain iron and zinc content in pearl millet (Pennisetum glaucum (L.) R. Br). Int J Trop Agric 33: 1387-1394.
5. Kanatti A, Rai KN, Radhika K, Govindaraj M, Sahrawat KL, et al. (2014a) Grain iron and zinc density in pearl millet: combining ability, heterosis and association with grain yield and grain size. Springerplus 3: 763
6. Cakmak I, Kutman UB (2017). Agronomic biofortification of cereals with zinc: a review. Eur. J. Soil Sci 69: 172-180.
7. Aro A, Alfthan G, Varo P (1995) Effects of supplementation of fertilizers on human selenium status in Finland. Analyst 120: 841-843.
8. Cakmak I (2009) Enrichment of fertilizers with zinc: an excellent investment for humanity and crop production in India. J. Trace elements Med. Biol 29: 281-289.
9. Prom-U-Thai C, Rashid A, Ram H, Zou C, Guilherme LRG, et al. (2020) Simultaneous biofortification of rice with zinc, iodine, iron and selenium through foliar treatment of a micronutrient cocktail in five countries. Front. Plant Sci 1516.
10. Yasin M, El Mehdawi AF, Jahn CE, Anwar A, Turner MF, et al. (2015b) Seleniferous soils as a source for production of selenium-enriched foods and potential of bacteria to enhance plant selenium uptake. Plant Soil 386: 385-394.
11. White PJ, Thompson JA, Wright G, Rasmussen SK (2017) Biofortifying Scottish potatoes with zinc. Plant Sci 411: 151-165.
12. White J, Broadley MR (2005) Biofortifying crops with essential mineral elements. Trends Plant Sci 10: 586-593.
13. Hefferon KL (2016) Can biofortified crops help attain food security?. Current Molecular Biology Reports 2: 180-185.
14. Hirschi KD (2009) Nutrient biofortification of food crops. Annual review of nutrition 29: 401-421.
15. Black RE, Allen LH, Bhutta ZA, Caulfield LE, De Onis M, et al. (2008) Maternal and child undernutrition: global and regional exposures and health consequences. The lancet 371: 243-260.
16. UNICEF WHO (2012) The World Bank Levels and trends in child mortality: report. Estimates Developed by the UN Inter-agency Group for Child Mortality Estimation.
17. Bhutta ZA (2008) Micronutrient needs of malnourished children. Current Opinion in Clinical Nutrition & Metabolic Care 11: 309-314.
18. Agrawal PK, Kohli A, Twyman RM, Christou P (2005) Transformation of plants with multiple cassettes generates simple transgene integration patterns and high expression levels. Mol Breed 16: 247-260.
19. Bhardwaj AK, Chejara S, Malik K, Kumar R, Kumar A, et al. (2022) Agronomic biofortification of food crops: An emerging opportunity for global food and nutritional security. Frontiers in Plant Science 13: 1055278.
20. 20. Bhaskaram P (2002) Micronutrient malnutrition, infection, and immunity: an overview. Nutrition reviews 60: 40-45.
21. Cakmak I, Kutman UÁ (2018) Agronomic biofortification of cereals with zinc: a review. European journal of soil science 69: 172-80.
22. Cakmak I, Kutman UÁ (2018) Agronomic biofortification of cereals with zinc: a review. European journal of soil science 69: 172-180.
23. Christou P, Twyman RM (2004) The potential of genetically enhanced plants to address food insecurity. Nutr Res Rev 17: 23-42.
24. Gousia Gani B, Bashir O, Bhat TA, Naseer B, Qadri T, Jan N. Hidden hunger and its prevention by food processing: A review.
25. Kapil U, Bhavna A (2002) Adverse effects of poor

micronutrient status during childhood and adolescence. Nutrition reviews 60: S84-S90.

26. Kiran A, Wakeel A, Mahmood K, Mubaraka R, Hafsa, et al. (2022) Biofortification of staple crops to alleviate human malnutrition: contributions and potential in developing countries. Agronomy 12: 452.
27. Meenakshi Gupta, Shipra Srivastava, Kahkashan Parvin, Faheem Khan, Sonam Gupta (2024) Biofortification of Solanum Tuberosum: A Rational Approach for Nutritional Security Int. J. of Adv. Res 412-422.
28. Miller DD, Welch RM (2013) Food system strategies for preventing micronutrient malnutrition. Food policy 42: 115-28.
29. Nestel P, Bouis HE, Meenakshi JV, Pfeiffer W (2006) Biofortification of staple food crops. The Journal of nutrition 136: 1064-1067.
30. Perez-Massot E, Banakar R, Gomez-Galera S, Zorrilla-Lopez U, Sanahuja G, et al. (2013) The contribution of transgenic plants to better health through improved nutrition: opportunities and constraints. Genes Nutr 8: 29-41.
31. Saltzman A, Birol E, Bouis HE, Boy E, De Moura FF, et al. (2013) Biofortification: progress toward a more nourishing future. Global food security 2: 9-17.
32. Sharma P, Aggarwal P, Kaur A (2017) Biofortification: A new approach to eradicate hidden hunger. Food Reviews International 33: 1-21.
33. Shewmaker CK, Sheehu JA, Daley M, Colburn S, Ke DY (1999) Seed-specific overexpression of phytoene synthase: increase in carotenoids and metabolic effects. Plant J 20: 41-412.
34. Singh U, Praharaj CS, Chaturvedi SK, Bohra A (2016) Biofortification: Introduction, approaches, limitations, and challenges. Biofortification of food crops 3-18.
35. Szerement J, Szatanik-Kloc A, Mokrzycki J (2022) Agronomic Biofortification with Se, Zn, and Fe: An Effective Strategy to Enhance Crop Nutritional Quality and Stress Defense—A Review. J Soil Sci Plant Nutr 22: 1129-1159.
36. White PJ, Broadley MR (2009) Biofortification of crops with seven mineral elements often lacking in human diets–iron, zinc, copper, calcium, magnesium, selenium and iodine. New phytologist 182: 49-84.
37. Yang SH, Moran DL, Jia HW, Bicar EH, Lee M, et al. (2002) Expression of a synthetic porcine alpha-lactalbumin gene in the kernels of transgenic maize. Transgenic Res 11: 11-20.
38. Ngozi UF (2013) The role of biofortification in the reduction of micronutrient food insecurity in developing countries. African Journal of Biotechnology 12.