Bio-Fortification: A Step Forward in Plant Nutrition for Crop Nutritional Quality and Productivity

Rida Chaudhry

Micronutrient deficiencies are typically caused by a lack of nutrient dense meals. The global burden of malnutrition continues to increase, with more than 768 million people suffering from hunger in 2020, that is 118 million more than that in 2019. As a result, nearly 320 million more people faced food insecurity in 2020 than in 2019, an increase of almost one third. Food fortification involves adding one or more micronutrients that the meal is deficient in to increase its nutritional value. The chapter highlights the importance of biofortification of crops to enhance crop nutritional profile by advanced agricultural practices (Agronomic biofortification, genetic engineering, traditional breeding) to diminish micronutrient deficiencies and thus micro-nutrient malnutrition and to combat hidden hunger. In order to fight with hidden hunger, many international agencies, national programs, and seed companies are developing bio-fortified crops. Harvest Plus, launched in 2006, brings together international and national efforts to improve the micronutrient levels of major staple crops. The chapter explores all the fundamental concepts and approaches of biofortification to increase crop nutritional value. The purpose of agronomic biofortification is to increase the proportion and bioavailability of nutrients in land or agricultural crops, in order to promote crop strength and productivity. Examples of some biofortified food crops are high iron beans, provitamin A maize, golden rice, zinc wheat, provitamin A orange fleshed sweet potatoes. Collaboration between government and corporate agencies is required to enhance biofortification for sustainable environmental development and to reduce malnutrition in society.

Keywords: *Bio-fortification, Micronutrients, Food, Crops, Agronomic biofortification*

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Introduction

Micronutrient deficiencies: Micronutrient deficits are generally caused by a lack of nutrient-dense meals, as well as mineral depletion due to insufficient nutrition, illnesses, and bleeding during menstruation. Micronutrient metabolism is particularly elevated during early stages of growth, gestation, and lactation. The World Health Organization, or WHO, has implemented some major techniques to improve nutritional consumption: Enhancement of food, vitamin and mineral supplementation, nutrition counseling, and preventative health approaches (Olson et al., 2021).

Food fortification: Fortification/Enrichment is a technique of increasing the nutritional value of food by introducing either one or more necessary micronutrients which are deficient in the meal. Food fortification is an effective means of giving deficient nutrients to the population, as long as the product chosen for fortification continues to be eaten by the most deprived people.

Global adoption of food fortification: To address the complicated nutritional deficiencies among humans, the government or non-governmental organizations may give the missing essential vitamins and minerals in the form of food-based items. Numerous countries have started food fortification. Foods can be supplemented with amino acid residues or concentrated protein isolates to improve protein utilization (Govindaraj, 2015).

Biofortification as a sustainable approach to combat malnutrition: Biofortification is the process of increasing the concentration of nutrients and antioxidants in key alimentary crops via genetic modification, traditional breeding, or conventional breeding. Biofortification of fundamental crops could be a successful and affordable approach to treat malnutrition, especially in low-income individuals who lack the majority of the crucial essential nutrients needed for their everyday meals (Yadav et al., 2020).

The Evolution and global impact of biofortification: bridging agriculture and nutrition

Early efforts to enhance nutritional content of food: From the beginning of 1964, researchers began enhancing maize protein content to combat hunger in communities in which maize was relatively primary dietary source. Funding in early nutritional fortification studies was considerably less than in other world-wide crop research activities intended to increase productivity and nutrient availability.

Green revolution and its impact on agriculture: The Green Revolution gave a substantial shift in agricultural methods and strategies, especially in the developing world, with a focus on increasing crop yield, particularly grains like wheat and rice in countries that were developing (Avnee et al., 2023). In the era of the Green Revolution (1966-1985), there had been substantial expenditure in crop examinations, construction projects and expansion of markets in developing nations suffering from food scarcity.

Challenges of green revolution era: Improved agricultural output effectively raised total energy expenditure for thousands of individuals. Yet, micronutrient deficiency kept going, so by the end of the century, almost 40% of the global population had vitamin deficiencies (Kellogg et al., 2022).

Harvest Plus: Harvest Plus, a nutritional fortification research initiative, was launched in 2006 has a significant stake in the noble mission of combating hidden hunger through the development and upscaling of nutrient-rich crops. The approach’s main benefit is that it maximizes the consumption patterns of staple commodities like rice and wheat. The campaign focuses on families with limited resources that cannot afford to purchase fortified foods, which are relatively expensive (Ramadas et al., 2020).

Global perspectives on malnutrition: challenges, strategies, and the double burden

Hidden Hunger: “Hidden hunger” refers to micronutrient deficiencies that occur without calorie deficit diets. Iron, zinc as well as iodine, and the antioxidant vitamin A are among the most commonly deficient micro nutrients in the food, which are frequently caused by eating an energy-dense but nutritionally deficient diet. Hidden hunger is believed to impact more than two billion people globally, primarily in countries with low or middle incomes (Lowe, 2021).

Malnutrition: Malnutrition encompasses both undernutrition (deficits) and overnutrition (imbalanced diets), including excessive intake of calories and inadequate consumption of micronutrient-rich food items. Over nutrition (being obese) indicates a positive balance of nutrients, whereas under nutrition shows a negative nutritional balance. FAO states undernourishment as consuming less than 1800 Kilo calories per day, the bare minimum that most individuals need to live a life that is productive and healthy (Meijers et al., 2010).

Malnutrition has generally been linked with child starvation, but the word now refers evenly to starved and excessively fed individuals. The focus has shifted from deprivation to overeating, and more specifically, erroneous dietary habits. According to the nutrition findings, thousands of people worldwide suffer from malnutrition mainly because they are overweight and have an excessive amount of sugar, sodium and a high cholesterol content in their bloodstreams (Rao & Annadana, 2017).

Global prevalence of malnutrition: Malnutrition is identified as a worldwide health issue, and it has worsen since the COVID-19 pandemic. In 2020, over 768 million people worldwide suffered hunger, approximately 118 million greater than that of 2019. Furthermore, in 2020, approximately 2.37 billion people (almost one-third of the world's population) experienced food insecurity, an increase of nearly 320 million individuals in a single year (Medina-Lozano & Díaz, 2022). In 2019 worldwide hunger index reached 20, with the mean score exceeding as much as 29 in South Asia and 28 in Sub-Saharan Africa. The three most often used food-based techniques to alleviate nutritional malnutrition are traditional fortification, bio-fortification, and nutritional modification (Kruger et al., 2020).

Global and local efforts to address malnutrition: There are numerous global and local efforts, that include the World Health Organization's (WHO) five double-duty actions and the UN's Sustainable Development Goals (SDG-2) "Zero Hunger" and (SDG-3) "Ensure healthy lives and promote well-being for all at all ages" that strive to eliminate every type of malnutrition. Moreover, the Food and Agriculture Organization's tactical roadmap is to guide for national malnutrition approaches. Despite significant progress in lowering stunting among kids under five in some areas, no nation has yet reversed increasing child obesity (Tan et al., 2024).

Biofortification initiatives to tackle hidden hunger: Many international agencies, national programs, and commercial seed firms are working to combat hidden hunger around the world by developing bio-fortified crops. Harvest Plus is a prominent program that combines international and national efforts to boost the micronutrient levels of important staple crops. Seven staple crops, including legumes, wheat, maize, sweet potatoes, rice, millet, and cassava are being focused. These were chosen using the bio fortification preference index (BPI) technique to establish the recommended crops suitable for providing the greatest possible benefits within a particular country (Okwuonu et al., 2021).

Biofortification: A sustainable solution to global micronutrient deficiency

Definition and scope of biofortification: Bio-fortification can be defined as the technique of increasing an element's bio-available concentration in edible parts of agricultural crops by genetic engineering or agronomic intervention, whereas genetic biofortification refers to the usage of any traditional breeding process or recombinant DNA technique to increase amount and bioavailability (Shahane & Shivay, 2022).

Impact of micronutrient deficiencies: Lacks of key micronutrients frequently have long-term detrimental and irreversible effects on human well-being. Iron deficiency anemia affects approximately 2 billion individuals worldwide (Jha & Warkentin, 2020). Little ones, pregnant women, and non-pregnant women are especially vulnerable. It can impair physical and intellectual growth while also lowering immunity. The suggested daily iron consumption ranges from 8 to 18 mg depending on age, body weight, and gender, with pregnant women receiving 30 mg per day (Vasconcelos et al., 2017).

Role of biofortification in addressing micronutrient deficiencies: Biofortification has emerged as an essential discipline for producing Zinc and Iron dense food grains. This method was shown to increase the concentration of specific micronutrients in common agricultural crops like wheat, maize, rice, and pearl millet as well.

Approaches to biofortification: Biofortification provides dietary stability in two realistic manners. The first approach is to ensure the enhancement of bio-available micronutrients into the alimentary part of the crops through genetic modification and the breeding process, and the second is to improve the amounts of an inadequate essential nutrients of an agricultural crop by applying fertilizer, that is commonly known as agronomic fortification (Melash et al., 2016).

Techniques of biofortification: agronomic, genetic, and conventional approaches

1. Agronomic biofortification

Agronomic biofortification: an overview: Agronomic biofortification is the use of mineral-based fertilizers in land or agricultural crops to raise the proportion and bioavailability of particular nutrients. Agronomic bio-fortification aims to improve mineral solubility and absorption (Ofori et al., 2022). Agronomic biofortification cannot succeed without optimal soil characteristics that improve accessibility of micro nutrients for crop utilization.

Comparison of organic and mineral fertilizers: Organic materials (plant residuals and animal faeces) serve to maintain the organic content of the soil, providing numerous benefits such as improved soil pattern, ability to exchange cations, and water retention capacity. Additionally, while organic materials give slower but consistent nutrient ejection, mineral-based fertilizers provide greater flexibility in terms of timing, placement, and application duration, allowing nutrient availability to be aligned with crop demand.

Use of Microorganisms: Mycorrhizal fungi alongside fertilizers, are commonly used for biofortification. *Bacillus aryabhattai* has been shown to be effective in Zinc bio fortification of wheat when utilized alongside organic fertilizers (Bhardwaj et al., 2022).

Foliar feeding as a biofortification strategy: Foliar feeding with essential micronutrients frequently promotes greater absorption of nutrients and effective distribution in consumable plant portions compared to soil fertilization, particularly in cereal and leafy greens. Foliar paths are often more successful at assuring plant absorption because they avoid soil hardening. The disadvantage of application to the foliage is that nutrients are quickly rinsed off by rainfall, and therefore they are more expensive as well as hard to deliver.

Alternative Micronutrient delivery methods: Other tactics for specific micronutrient delivery, such as seed preparation and seed coatings with fertilizers, can accelerate growth of plants and boost yields, although improved nutritive qualities of crops are rare (De Valença et al., 2017).

2. Genetic engineering

Genetic engineering as a solution for biofortification: When there are insufficient variations in genes for the intended trait within the group of plants, or when the crop by itself is unsuitable for traditional breeding (because of the absence of sexual activity; for example, banana), genetic engineering provides a viable option for enhancing the levels and accessibility of micronutrients in consumable crop tissue layers. One of the primary problems is referred as "genetic flow "environment-related issue, which refers to the transmission of foreign DNA towards unwanted species.

Examples of genetically engineered biofortified crops: By way of example, one of the very first crops to become biofortified was the golden rice, that had been bred for producing vitamin A or the antioxidant beta-carotene within the consumable section of the kernel. This method is also being used on other agricultural products, such as maize, potatoes, orange, the cauliflower plant, tomatoes, and golden canola (Prasad et al., 2015).

3. Conventional breeding

Conventional breeding: an overview: It is the process of developing new crop varieties using traditional procedures rather than using modern molecular plant biological instruments (Shahzad et al., 2021). Conventional breeding is limited, however, because it can only use the genetic variability already available and observable in the crop being improved or occasionally in the wild varieties that can cross with the crop. Furthermore, conventional breeders usually have to trade away yield and sometimes grain quality to obtain higher levels of nutrition.

Examples of conventional breeding: One example is quality protein maize (QPM), which has taken decades of conventional plant breeding work to develop into varieties acceptable to farmers. Yet, additional gains are sometimes attainable, such as zinc and iron in wheat and rice, where the features that cause greater levels of zinc along with iron in the crop can also result in a greater yield, according to some studies (Singh et al., 2016).

Examples of Biofortified Food Crops
1. Golden Rice

Global significance of rice as a staple crop: Over fifty percent of the world's population consumes rice, which accounts for over 42 percent of their daily calorie consumption. Rice is the most rapidly expanding primary crop across Africa as well as, Latin America and makes up around 90% of worldwide consumption in Asia.

Nutritional Composition of rice: The nutritional value of rice includes many vitamins (that includes B1, B2, and B6), a variety of phytochemicals, and minerals such as iron, copper, zinc, sodium, potassium, magnesium, and phosphorus (Dhaliwal et al., 2022).

Golden rice as a strategic intervention: Golden rice is a genetically modified crop that yields a compound called beta-carotene in the kernel. The antioxidant beta-carotene is turned to vitamin A in the body of humans. Golden rice was created as a tactic to treat the lack of vitamin A, which is common in many places in which rice is a major meal (Ashoka et al., 2023).

2. High iron beans

High iron beans were developed utilizing conventional breeding techniques to assist to treat iron shortage. These beans contain about double the amount of iron of normal beans that had been distributed in various countries, including Rwanda and the Democratic Republic of the Congo, demonstrating encouraging results in increasing person's iron intake (Junqueira-Franco et al., 2018).

3. Zinc wheat

Zinc wheat has been produced through traditional breeding procedures to increase zinc content. The zinc level of wheat can be raised effectively by fertilizing the crops using zinc salts such as foliar treatment of $ZnSO_4$ boosted overall zinc content by around 60% than ordinary wheat, which contributed immensely to the daily zinc demand (Balk et al., 2019).The Organizations like Harvest plus, International maize & wheat improvement center (CIMMYT) and gene bank laid the groundwork for producing competitive bread wheat varieties having 40% greater Zn concentrations in the South Asian region (Kiran et al., 2022).

4. Provitamin A maize

Bio-fortified maize by provitamin A seems to be a potent source of vitamin A when taken as a primary crop. Research carried out in Zambia on 5-7 years old kids found that shortly following 90 days of usage, the kids belonging to the orange maize category had considerably higher total body reserves of vitamin A versus those in the vehicle group. Intake of orange maize is believed to increase the body's overall vitamin A reserves just as efficiently as dietary supplementation, as well as considerably improvement in visual performance in children with minor vitamin A deficiencies (Bouis& Saltzman, 2017).

5. Provitamin A rich Orange-fleshed sweet potatoes

The main supporting data for biofortification's efficacy is based upon significant randomized controlled experiments using provitamin A-rich orange-fleshed sweet potatoes that reached 24000 families in Uganda and Mozambique between the years 2006 and 2009. The widespread use of orange-fleshed sweet potatoes in the countryside of Uganda raised vitamin A consumption amongst kids and their moms while further enhancing vitamin A status among youngsters. Women who consumed greater amounts of antioxidant (vitamin A) by the produce were also less likely to have minor vitamin A insufficiency (Osendarp et al., 2018).

Challenges and constraints in achieving effective biofortification

Agronomic biofortification: opportunities and limitations: The simplest method for developing biofortified crop varieties is the agronomic approach by utilizing micronutrient-fortified fertilizers, but it is extremely unpredictable due to the altering patterns of mineral transportation and accumulation across various crop varieties, as well as variable soil compositions in different geographical locations. Moreover, it is a costly and labor-intensive strategy because it requires constant micronutrient inputs to the plant and soil on a regular basis (Sheoran et al., 2022).

Challenges in developing micronutrient rich crop varieties: Producing micronutrient-rich cultivars involves a number of distinct challenges. Seeds should be grown, carried, and distributed to agriculturalists, and farmers must be willing to use these seeds. All of these actions must take place on time due to the changing patterns of agricultural production, particularly in countries like Ethiopia, where agricultural production is primarily rain-fed.

Geographical and environmental constraints: The fact that biofortification success is dependent on an efficient seedling mechanism, which has major challenges regardless of the biofortification purpose, which brings another aspect to the attempt to mainstream bio-fortification (Bachewe et al., 2023).

Conclusion

Micronutrient deficiencies are caused due to lack of nutrients in the diet. To comply with this fortification of food with specific micronutrients is necessary. Biofortification is the technique of boosting the content of nutrients and antioxidants in essential food crops by genetic alteration or traditional breeding. The Green Revolution was launched to boost the agricultural output of certain crops in underdeveloped countries. Harvest Plus was a similar project with the goal of fighting hidden hunger and improving the nutritional profiles of specific crops. The initiative targets low-income families who cannot afford to buy fortified foods. Initially, agronomic approaches were used to increase crop health and productivity, but this cannot be achieved without ideal soil qualities. Water retention capacity of soil and its pattern can be increased by plant residues and animal faeces. But its cost, labor and changing patterns of agriculture made it a little challenging to adopt by farmers. Public and private entities should collaborate and initiate such campaigns that promote bio-fortification practices to fight with malnutrition. Government should implement programs to educate farmers about biofortification practices for maintaining a sustainable ecosystem. Regulatory authorities should monitor and evaluate the effectiveness and impact of biofortification programs.

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