

Biofortified Vegetables for Nutritional Security

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INTRODUCTION

Malnutrition continues to be a major global challenge despite significant advances in agricultural production and food availability. While many countries have achieved improvements in food security in terms of caloric intake, deficiencies of essential micronutrients remain widespread. This phenomenon, commonly known as hidden hunger, results from inadequate consumption of essential vitamins and minerals required for proper physiological functioning. Micronutrient deficiencies such as iron, zinc, iodine, and vitamin A deficiency affect millions of people, particularly in developing countries where diets are often dominated by staple cereals with low micronutrient density. These deficiencies can lead to severe health consequences including anemia, weakened immunity, impaired cognitive development, and increased risk of morbidity and mortality.

Vegetables play a crucial role in human nutrition because they are rich sources of vitamins, minerals, dietary fiber, antioxidants, and various bioactive compounds. Regular consumption of vegetables contributes to improved health outcomes and reduced risk of chronic diseases such as cardiovascular disorders, diabetes, and certain cancers. However, the nutrient content of vegetables can vary widely depending on soil fertility, environmental conditions, crop varieties, and agricultural practices. In many cases, the micronutrient concentrations present in vegetables may not be sufficient to meet the recommended dietary requirements of vulnerable populations.

2. Concept of Nutritional Security

Nutritional security refers to the condition in which individuals have consistent access to sufficient, safe, and nutritious food that meets their dietary requirements for a healthy and active life. While food security focuses primarily on the availability of adequate quantities of food, nutritional security emphasizes the quality of food and the presence of essential nutrients necessary for optimal health and development.

Nutritional security is based on four key components: food availability, food accessibility, food utilization, and stability of food supply. Food availability refers to the presence of adequate food supplies within a region or country, whereas food accessibility relates to the ability of individuals to obtain these foods through economic or physical means. Food utilization involves proper biological use of nutrients through balanced diets, safe food preparation, and adequate health conditions. Stability ensures that these factors remain consistent over time without being affected by economic, environmental, or social disruptions.

3. Biofortification: Definition and Importance

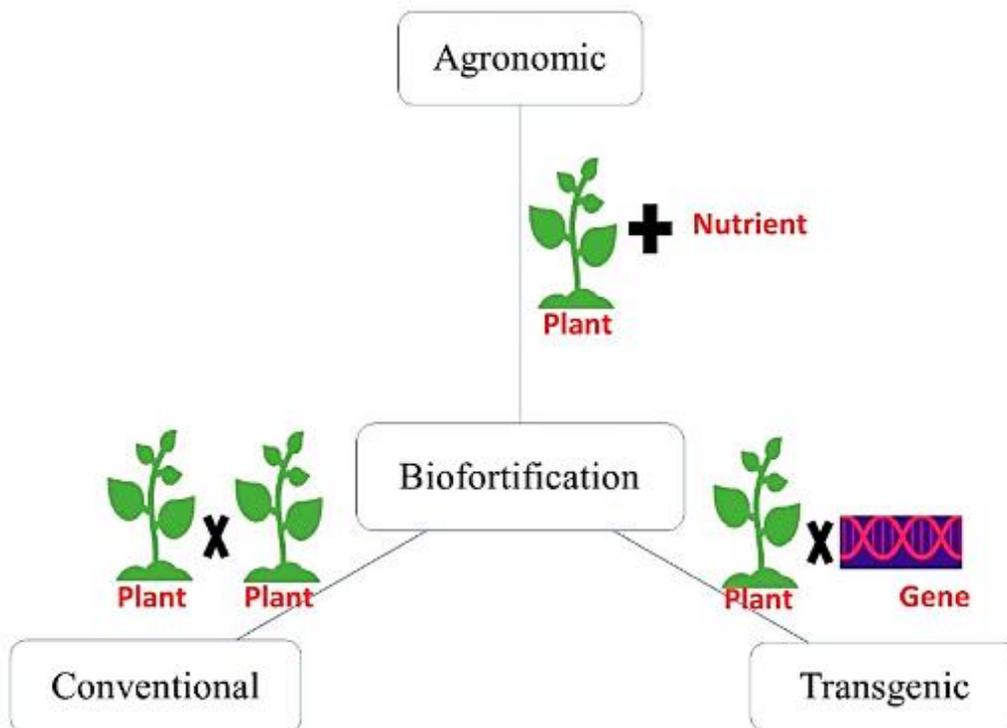
Biofortification refers to the process of enhancing the nutritional quality of food crops by increasing their content of essential vitamins and minerals through biological approaches. These approaches may include conventional plant breeding, agronomic practices such as micronutrient fertilization, or advanced biotechnological methods such as genetic engineering and genome editing. The primary objective of biofortification is to develop crop varieties that naturally contain higher levels of nutrients in their edible parts, thereby improving the nutritional status of populations that consume them regularly.



The key objectives of biofortification include increasing the concentration of micronutrients in edible plant tissues, improving the bioavailability of these nutrients for human absorption, reducing the prevalence of micronutrient deficiencies, and promoting sustainable agricultural practices. Biofortification also supports global efforts to

improve food systems by integrating nutrition goals into crop improvement programs.

Overall, biofortification represents a powerful strategy for improving the nutritional quality of food crops and enhancing global food and nutritional security.



4. Approaches to Biofortification

Biofortification can be achieved through several approaches that aim to enhance the nutrient content of crops during plant growth. The three major approaches include agronomic biofortification, conventional plant breeding and modern biotechnological methods.

4.1 Agronomic Biofortification

Agronomic biofortification involves the application of mineral fertilizers, soil amendments, or nutrient solutions to increase the concentration of micronutrients in crops. This approach enhances nutrient availability in soil and promotes greater uptake by plant roots. Micronutrients such as zinc, iron, and selenium can be supplied through soil fertilization or foliar sprays to increase their accumulation in edible plant tissues.

For example, zinc fertilization in spinach, selenium fertilization in garlic, and iron supplementation in leafy vegetables have shown significant improvements in micronutrient content. Agronomic biofortification is relatively simple to implement and can be integrated with existing agricultural practices. In recent years, nanotechnology-based fertilizers have also been

explored as innovative tools for improving micronutrient delivery and uptake efficiency in plants.

4.2 Conventional Plant Breeding

Conventional plant breeding is another widely used approach for developing biofortified crops. This method involves identifying and crossing plant varieties with naturally high nutrient content to produce improved cultivars with enhanced micronutrient levels. The process typically includes germplasm screening, hybridization, selection, and evaluation of progenies under different environmental conditions.

4.3 Genetic Engineering and Genome Editing

Modern biotechnology provides advanced tools for enhancing nutrient accumulation in crops. Genetic engineering allows the introduction or modification of genes responsible for nutrient synthesis, storage, or transport within plants. For instance, genes involved in beta-carotene synthesis can be manipulated to increase provitamin A levels in vegetables.

5. Importance of Biofortified Vegetables

Biofortified vegetables possess several advantages that make them particularly suitable

for addressing micronutrient deficiencies. First, vegetables are naturally rich in vitamins and minerals, making them ideal vehicles for delivering additional micronutrients through biofortification. Second, most vegetable crops have relatively short growth cycles, allowing rapid development and dissemination of improved varieties compared with staple crops. Third, vegetables often exhibit high productivity per unit area and can be cultivated intensively in

small landholdings. Furthermore, many vegetable crops can be grown in homestead gardens, kitchen gardens, and urban farming systems, enabling households to produce nutrient-rich foods locally. Biofortified vegetables can therefore play an important role in improving dietary diversity and increasing the intake of essential micronutrients among vulnerable populations, particularly children and women of reproductive age.

			
Bhu Krishna (Sweet potato)	Bhu Kanti (Sweet potato)	Bhu Sona (Sweet potato)	Sree Neelima (Greater Yam)
			
Pusa Beta Kesari (Cauliflower)	Pusa Jamuni (Radish)	Pusa Gulabi (Radish)	Pusa Ashita (Black carrot)
			
MS/8-1565 (Kufri Neelkanth) Potato	Pusa Kulfi (yellow carrot)	Pusa Rudhira (red carrot)	Pusa Meghali (orange carrot)

6. Major Biofortified Vegetable Crops

Several vegetable crops have been successfully targeted for biofortification in order to enhance their micronutrient content and improve their contribution to human nutrition. Different approaches such as agronomic fertilization, plant breeding, and genetic engineering have been employed to increase the concentration of key

nutrients including iron, zinc, beta-carotene, and other vitamins in edible plant tissues. Leafy vegetables, root vegetables, and tuber crops are particularly suitable candidates for biofortification because they are widely consumed and contain relatively high levels of micronutrients.

Table 1. Important Biofortified Vegetables and Target Nutrients

Vegetable Crop	Target Nutrient	Method Used	Example
Spinach	Iron	Agronomic biofortification	Fe fertilization
Carrot	Beta-carotene	Breeding	Orange carrot varieties
Tomato	Vitamin A	Genetic engineering	Provitamin A enriched tomatoes
Potato	Iron, Zinc	Breeding & biotechnology	High-Fe potato
Sweet potato	Beta-carotene	Conventional breeding	Orange-fleshed sweet potato
Lettuce	Iron	Hydroponic enrichment	Fe-enriched lettuce

7. Micronutrients Targeted in Vegetable Biofortification

Micronutrients play essential roles in maintaining human health and physiological functions. Several key micronutrients have been targeted for enhancement in vegetable crops through

biofortification strategies. Among these, iron, zinc, vitamin A, selenium, and folate are particularly important because their deficiencies are widespread and pose serious public health challenges.

Table 2. Key Micronutrients and Their Functions

Micronutrient	Function in Human Health	Deficiency Symptoms
Iron	Hemoglobin formation	Anemia
Zinc	Immune function	Growth retardation
Vitamin A	Vision and immunity	Night blindness
Selenium	Antioxidant defense	Cardiovascular disorders
Folate	DNA synthesis	Neural tube defects

8. Techniques Used in Vegetable Biofortification

Several techniques have been developed to increase the micronutrient content of vegetable crops. These techniques aim to enhance nutrient availability in soil, improve plant uptake, and promote accumulation of essential micronutrients in edible plant tissues.

One of the most common techniques is soil fertilization, which involves the application of micronutrient fertilizers directly to the soil. This method increases the availability of nutrients such as zinc, iron, and selenium for plant uptake. Another widely used technique is foliar application, where nutrient solutions are sprayed directly onto plant leaves. Foliar fertilization allows rapid absorption of micronutrients and can significantly increase their concentration in plant tissues.

9. Role of Soil Plant Microbe Interaction

Soil-plant-microbe interactions play a crucial role in determining the availability and uptake of nutrients in agricultural systems. The rhizosphere, which is the region of soil surrounding plant roots, hosts a diverse community of microorganisms that influence nutrient cycling and plant growth. These microorganisms can enhance nutrient availability by solubilizing minerals, fixing atmospheric nitrogen, and producing growth-promoting substances.

Mycorrhizal fungi form symbiotic associations with plant roots and improve the uptake of nutrients such as phosphorus and micronutrients from the soil. Similarly, plant growth-promoting

rhizobacteria (PGPR) can enhance nutrient availability by producing organic acids and enzymes that mobilize micronutrients in the soil. These microorganisms also stimulate plant growth and improve resistance to environmental stresses.

Maintaining healthy soil microbial communities is therefore essential for the success of biofortification strategies. Integrating microbial inoculants with agronomic biofortification practices can enhance nutrient uptake efficiency and improve the nutritional quality of vegetable crops.

10. Role of Biofortified Vegetables in Nutritional Security

Biofortified vegetables have the potential to play a significant role in improving nutritional security, particularly in developing countries where micronutrient deficiencies are prevalent. By increasing the nutrient content of commonly consumed vegetables, biofortification helps improve dietary quality and provides an accessible source of essential vitamins and minerals. Regular consumption of biofortified vegetables can enhance micronutrient intake, support immune function, and promote overall health.

12. Advantages of Biofortification

Biofortification offers several advantages compared with other nutritional interventions such as food fortification and dietary supplementation. It is a sustainable and cost-effective strategy because once nutrient-dense crop varieties are developed; they can be cultivated repeatedly without additional

investment. Biofortified crops also reach rural populations who may have limited access to commercially fortified foods.

13. Challenges and Limitations

Despite its potential benefits, biofortification faces several challenges that may limit its widespread adoption. One of the major challenges is the interaction between genotype and environmental factors, which can influence nutrient accumulation in crops. Soil properties, climate conditions, and agricultural practices can all affect the effectiveness of biofortification strategies.

14. Future Prospects

Future research and technological advancements are expected to further enhance the potential of biofortification in improving nutritional security. Emerging technologies such as genome editing using CRISPR-Cas systems offer new opportunities for precise modification of plant genes involved in nutrient uptake and metabolism. Nanotechnology-based fertilizers are also being developed to improve nutrient delivery efficiency and reduce environmental impacts.

CONCLUSION

Biofortification of vegetable crops represents a promising and sustainable strategy for addressing micronutrient malnutrition and improving global nutritional security. Through approaches such as agronomic fertilization, plant breeding, and modern biotechnology, vegetables can be enriched with essential micronutrients including iron, zinc, vitamin A, and selenium. Biofortified vegetables provide an effective and long-term solution to hidden hunger, particularly in developing countries where access to diversified diets and fortified foods may be limited.

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