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Breeding Crops for Better Nutrition: Current Development in Biofortification Research

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The world population is anticipated to rise from 7.87 billion in 2021 to 8.6 and 9.8 billion by 2030 and 2050, respectively.The agricultural production and supply chain are the most vulnerable to current global crises like climate change and the COVID-19 pandemic. The pandemic has already placed a serious burden on human health worldwide and its indirect effects such as interruptions in food production, transport and distribution are likely to increase hunger and malnutrition, especially in developing nations. These disruptions are adding further pressure to the already growing concerns about global food security(Sheoran *et al.*, 2022). Humans need an adequate and balanced supply of food and nutrients for proper growth and overall development.The United Nations (UN) 2nd Sustainable Development Goal was set to eradicate extreme hunger and malnutrition whilst promoting food security. However, rapid population growth and the effects of climate change are making this goal difficult to achieve. In many regions, food availability is insufficient to meet the needs of the growing population, resulting in rising levels of hunger. Malnutrition occurs when the body does not receive nutrients in the right balance, which can lead to various health problems(Ofori*et al.*, 2022). Biofortification refers to improving the nutritional quality of food crops by increasing their natural content of essential vitamins and minerals such as iron, zinc and vitamin A. This can be done through traditional plant breeding; better farming practices like adding mineral fertilizers, or through modern biotechnological methods. Unlike food fortification, where nutrients are added during processing, biofortification boosts the nutrient levels in the crop itself while it is still growing in the field.

Apporches to Biofortification

1. Conventional Plant Breeding

Conventional breeding is one of the most widely used and accepted methods for developing biofortified crops. This approach improves the nutritional quality of crops while maintaining important agronomic traits such as yield, growth and resilience. Biofortification through conventional breeding involves crossing crops with genotypic characteristics of high nutrient density and other agronomic traits to produce new varieties with desirable nutrient and agronomic traits(Ofori*et al.*, 2022).

Table1.Biofortified crop varieties developed through conventional plant breeding (Sheoran*et al.*, 2022).

Crop	Targeted Nutrient	Variety	Country
Rice	Zn	DRRDhan49, DRRDhan48, DRRDhan45	India
Wheat	Fe, Zn and protein	PusaTejas(HI 8759) (durum), MACS4028 (durum)	India
Pearlmillet	Fe and Zn	HHB299, AHB 1269Fe, ABV04, Phule Mahashakti, RHB233, RHB 234, Dhanashakti	India
Cowpea	Fe	PantLobia-1, PantLobia-2, PantLobia-3, PantLobia-4, PantLobia-7,	India
Mustard	Erucicacid and Glucosinolates	Pusa Double Zero, Mustard31	India

2. Agronomic Biofortification

Agronomic biofortification focuses on improving the micronutrient content of edible crops through specific farming practices. In this approach, nutrients are supplied directly to the soil or plant to enhance their uptake. The aim of the study was to increase the nutritional value of the edible plant parts by using methods such as applying zinc through foliar sprays of $ZnSO_4$, adding iodine to the soil in the form of iodate or iodide and supplying selenium as selenite(Naik *et al.*, 2024).

3. Molecular Breeding

The general procedure for the development of a biofortified variety is the identification and transfer of desirable genes from a donor to a recipient parental line that is agronomically superior via molecular breeding tools. Advances in molecular breeding have made it faster and more efficient to create crop varieties enriched with essential minerals that can help reduce malnutrition. By studying the genetic makeup of different germplasm lines, researchers can identify specific genes or quantitative trait loci (QTLs) linked to important micronutrients such as carotenoids, iron, zinc and essential amino acids in crops like rice, wheat, maize and pearl millet (Sheoran *et al.*, 2022).

4. Genetic Engineering

Plant breeding depends on the natural genetic variation present within crop species. When this variation is limited, it becomes difficult to improve crops through conventional breeding, including efforts toward biofortification. In contrast, genetic engineering is not restricted to crossing related plant species. It offers a practical solution by allowing the introduction of useful traits from diverse sources. This approach has successfully improved crops like banana and rice, which are difficult to enhance through traditional breeding methods. Genetic engineering provides the platform for introducing nutrient or agronomic traits new to specific crop varieties by applying plant breeding and biotechnology principles and when employed in biofortification(Ofori *et al.*, 2022).

Genetic engineering becomes the preferred method when crops lack sufficient natural genetic variation for improving essential nutrients. This technique allows the transfer or overexpression of useful traits from unrelated plant species or even from organisms such as bacteria into major food crops, regardless of their taxonomic or evolutionary relationships. Through genetic engineering, specific genes can be introduced directly into high-performing cultivars to increase their nutrient content. This can be achieved in two main ways: by altering the pathways involved in nutrient uptake and use or by improving nutrient bioavailability and reducing anti-nutritional compounds(Sheoran *et al.*, 2022).

Table 2.Some examples of biofortified crops produced by transgenesis.

Crop	Gene/Protein	Target
Soybean	Phytoene synthase crt B FATB1-A and FAD 2- 1A	B-carotene Reduced linoleic acid
Maize	Aspergillusnigerphy A2 Corynebacterium glutamicum cordap A	Phytatedegradation Lysine
Rice	C1 and R-SPAL, F3H, ANS, CHS and DFR OsIRT1	Flavonoids Zinc
Sweet potato	Crtl, CrtB, CrtY, LCYe	B-carotene
Banana	Phytoene synthase PSY2a	B-carotene
Wheat	Ferritin TaFer Silencing SBElla	Iron Amylose
Potato	nptII	Amylopectin component of starch
Tomato	HMT, S3H, and SAMT GDP-l-galactose phosphorylase	Iodine Vitamin C
Barley	AtZIP1	Iron, Zinc

Limitations

Phytates and tannins are major compounds that reduce the body's ability to absorb minerals like iron, zinc and calcium. Although phytate is present in many plant tissues, it is found in the highest amounts in seeds and grains. There is considerable intraspecific variation in phytate concentration in edible portions. Phytic acid and related plant compounds, such as PP, are considered "anti-nutrients" because they bind to minerals especially iron and make them harder for the human digestive system to absorb(Singh *et al*., 2016). Furthermore, crop phenotype, genotype and soil conditions are additional factors that influence the effectiveness of fertilizers to biofortify crops. Studies have shown that differences in nutrient uptake, movement within the plant and overall nutrient accumulation are largely influenced by the plant's genetic makeup(Marques *et al*., 2021).

Conclusions

Fortification is a tool that has been used successfully to correct nutrient inadequacies and their associated deficiencies. This approach is commonly applied through mandatory fortification of staple foods. In recent years, the purpose of fortification has expanded from merely preventing deficiencies to also promoting better overall health. However, the benefits of voluntary or discretionary fortification are still uncertain and its long-term impacts are not well understood. Because fortified foods are widely consumed, fortification increases nutrient intake for almost the entire population.

Future Prospective

There is a growing need to involve all relevant stakeholders in recognizing the importance of maintaining more complete and updated databases on food consumption, nutrient intake and biomarkers linked to nutritional status. Such information is essential for accurately assessing population nutrition and guiding effective health and nutrition policies (Dwyer *et al*., 2015). Integrating agronomic approaches with genetic strategies can help improve the movement of minerals into plant tissues that are supplied through the phloem. Understanding the mechanisms that control mineral balance within plant cells is also important, as this knowledge can be used to raise the levels of essential micronutrients in edible parts of crops(Sheoran *et al*., 2022).

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