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Biofortification: Importance in Agriculture and Future Approach

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Humans need food and nutrients in the correct amount to ensure proper growth and development. The Sustainable Development Goal (SDG) of the United Nations (UN) was established to end severe hunger and malnutrition while enhancing food security. Food fortification, especially biofortification, has been predicted to be the most innovative intervention, despite the fact that dietary diversity and food supplementation have been employed as intervention strategies. Increasing the amounts and bio-accessibility of nutrients in food crops while they grow is one of the strategies of biofortification. The Harvest plus Program was launched in 2003 with the goal of ensuring the availability of high-quality biofortified staple types. Orange-fleshed sweet potatoes (OFSP), golden rice, yellow and orange maize biofortified with vitamin A, wheat and rice biofortified with Zn and Fe, and beans biofortified with Fe are typical examples of biofortified crops through this initiative. Plant Based Foods (PBFs) make up a larger portion of some people' diets; therefore biofortification is an important to fight against hidden hunger and malnutrition.

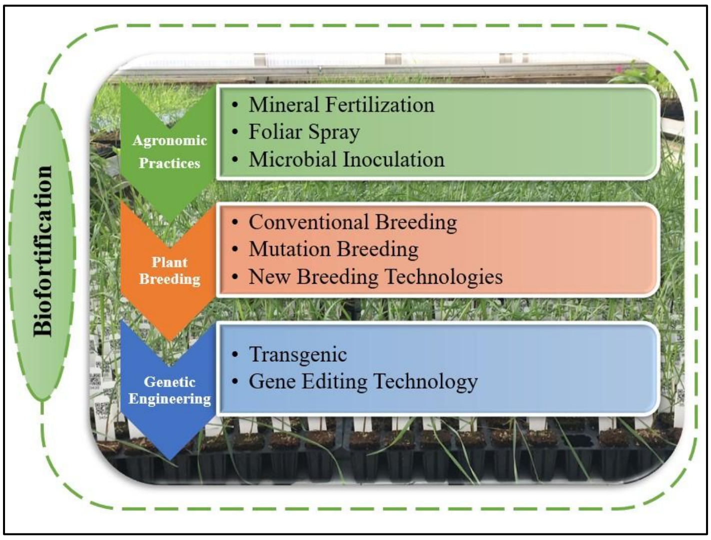

Fig 1. Different approaches of Biofortification

Agronomic, plant breeding and genetic engineering are some important strategies for improving the food quality via fortification to ensure the food security of the nation. By exploiting the genetic variations between crops of similar species, biofortification through plant breeding seeks to increase the amount and bio-accessibility of minerals in crops. Plant breeding techniques may not be able to biofortify some crops due to lack of wider genetic variability among them. Alternatively, the transgenic approach entails identifying and assessing suitable genes that could be added to these crops to raise their nutritional content. Since using these three strategies, grains, legumes, oilseeds, vegetables, and fruits crops have been biofortified.

Biofortification through agronomic practices

Agriculture provides the majority of human nutrition, especially for the people living in poor nations. Cereals including wheat, maize, rice, and cassava are the main sources of nutrition in the majority of the world. They have insufficient quantities of vitamins or minerals therefore to increase the micronutrient of staple crops agronomic biofortification is a good approach. Some of the micronutrients are usually used as fertilizers to increase the plant's absorption of the micronutrients. The plant's numerous metabolic activities also need these micronutrients (Ahmad *et al*., 2017).

Another approach that is becoming more and more popular is incorporation of plant growth-promoting bacteria (PGPR) into the soil. These microbes help plants by improving water uptake, assisting in the assimilation of nutrients, and releasing hormones, antibiotics, and secondary metabolites agronomic biofortification is a process to enhance micronutrients in the food crops through agronomic approaches. Agronomic biofortification is a strategy to improve the micronutrients in staple food crops like rice, millet, sorghum, wheat, maize, cassava, and sweet potatoes, is a quick and efficient way to fix soil. Tillage is a fascinating method of preparing soil and land that farmers employ often to encourage improved plant development. When compared to human-powered tillage methods, mechanical tillage is the fastest way to combine soil with organic matter and inorganic fertilizers. The process makes the upper layer of the soil smooth, aids in the release of nutrients by the decomposition of organic matter, creates soil aeration, provides the perfect texture to sow seeds, and removes weeds and hard/compact soil. Even in adverse circumstances, the combination of tillage, the use of organic fertilizers, and a small number of inorganic fertilizers helps to achieve the required crop nutritional value and soil fertility. Foliar application is preferable to soil application since there is very little chance of micronutrient loss with this method and the micronutrients are absorbed directly by the plant tissues especially in the Maize, Rice and Wheat. For grain, foliar spraying at a later stage is more advantageous that foliar Zn application after blooming and throughout the early milk and dough stages increased grain Zn content higher than other prior applications. In alkaline soils, foliar Zn spraying increased test weight and grain protein content without affecting biological yield. Foliar Zn application increased grain Zn and Fe concentrations by 99% and 8%, respectively, while foliar Mn application increased grain Mn content by 7percent.

Biofortification through plant breeding

The most popular and widely recognized method of plant breeding for biofortification is conventional breeding. Without sacrificing other agronomic traits, conventional breeding improves the nutritional values of crops. In order to produce new varieties with desired nutrient and agronomic traits, biofortification through conventional breeding entails crossing crops with genotypic characteristics of high nutrient density and other agronomic properties. It entails identifying crop varieties that are biodiverse, evaluating the traits and concentrations of target nutrients in these varieties, and figuring out how growing conditions affect the stability of these traits. In contrast to conventional breeding, mutation breeding introduces mutations through chemical treatments or physical procedures like irradiation, which results in variances in genetic traits among crops. In molecular breeding to achieve biofortification the location of a gene that enhances nutritional quality is determined, along with markers that are closely linked with that particular gene. Conventional breeding techniques can then be employed to incorporate the desired features into the crop with the help of the marker. To ascertain whether a desired trait is present or absent in a particular crop at a certain developmental stage, molecular breeding can be employed. Due to this, it is quicker than other methods of plant breeding (Sheoran et al. 2022).

However, cultivating varieties with both desirable traits such as nutrient density and agronomic traits—takes longer and requires more labor in conventional breeding. Furthermore, it might be hard to biofortify crops that lack genetic variations through plant breeding, and it might not work for all nutrients. Furthermore, crops that are vegetatively propagated like bananas are unsuitable for conventional breeding. However, cultivating varieties with both desirable traits such as nutrient density and agronomic traits—takes longer and requires more labor in conventional breeding. Furthermore, it might be hard to biofortify crops that lack genetic variations through plant breeding, and it might not work for all nutrients. Furthermore, crops that are vegetatively propagated—like bananas are unsuitable for conventional breeding.

Biofortification through genetic engineering

Biofortification through genetic engineering involves the use of advanced biotechnological techniques to enhance the nutritional profile of crop. It allows the transfer of genes from one organism to another, even if they are evolutionarily and taxonomically distinct. In this technique novel genes have been introduced, existing genes over expressed, down or up regulated the genes, or synthesis pathway genes of inhibitors to create transgenic crops. Awell-known example of biofortification through genetic engineering is Golden Rice, which has been engineered to produce beta-carotene, a precursor of vitamin A which is more prevalent in many developing countries.One of the recent and advanced genetic engineering technology is CRISPR-Cas9genome editing (Fig. 2) that provides new opportunities for the development of biofortified crops through modification by adding and deleting or edit plant genes which were involved in nutrient uptake, transport, and storage that holds for enhancing the nutritional value of major crops. The CRISPR-based genome-editing technique has revolutionized genetic engineering by enabling rapid, DNA/transgene-free, and targeted multiplex genetic modifications, which are crucial for developing "golden" staple crops. Its efficiency, precision, and ability to make targeted modifications without inserting foreign DNA make it a favorable option for biofortification. This approach has been particularly effective in producing carotenoid- biofortified crops, which aim to combat Vitamin A Deficiency. By leveraging this technology, we can develop crops that not only meet the nutritional needs of a growing global population but also gain greater acceptance from regulators and the public, paving the way for a healthier future.

Biofortification success stories in India

The nutritional quality of high-yielding cereal cultivars has been improved by the Indian Council of Agricultural Research, National Research Institutes, and State Agricultural Universities, using many traditional and cutting-edge breeding techniques to produce fruits, vegetables, oilseeds, legumes, and fruits (Yadava *et al.*, 2019). A specific project on the Consortium Research Platform on Biofortification in Selected Crops for Nutritional Security was launched in the 2010 as part of the ICAR's 12th Plan, marking the beginning of dedicated efforts towards biofortification There are now 71 biofortified varieties of wheat, maize, pearl millet, rice, finger millet, mustard, soybean, lentil, groundnut, potato, sweet potato, greater yam, small millet, linseed, cauliflower, and pomegranate. Wheat has produced the greatest number of biofortified varieties, following maize, rice, and pearl millet, and maximum iron content was observed, followed by protein, zinc, lysine, tryptophan, and other important minerals. Furthermore, a significant amount of advanced elite materials is being developed and will be made available eventually. In order to ensure the nation's nutritional security, these biofortified cultivars are extremely important. To increase the mass awareness of these biofortified cultivars, extra efforts are being done. High-quality biofortified variety seeds are being created and supplied for use in commercial agriculture. The ICAR's Extension Division has also started two unique initiatives, called Value Addition and Technology Incubation Centers in Agriculture (VATICA) and Nutri-sensitive Agricultural Resources and Innovations (NARI), to help its Krishi Vigyan Kendras (KVKs) scale up biofortified varieties. The creation of biofortified staple foods is a continual effort being under taken by various agencies such as DBT, ICMR, HarvestPlus, and CSIR.

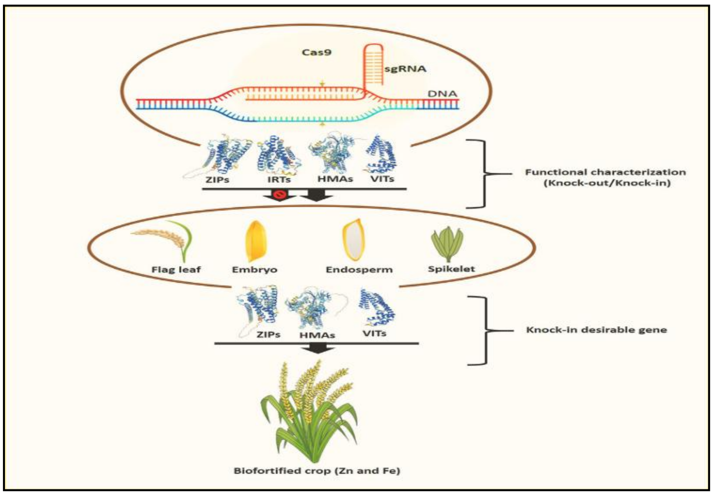

Fig 2. Crop biofortification using CRISPR-Cas9 Genome Editing Technology, (Krishna *et al.*2023)

Conclusion

Micronutrient deficiencies, primarily in vitamins and minerals, are a global concern leading to diseases, especially among women and children. Therefore, food fortification emerges as a crucial and practical strategy to combat malnutrition, particularly in developing nations. The success and sustainability of biofortification hinge on breeding techniques that enhance nutrient levels without compromising yield, farmer acceptance of biofortified crop production, and consumer adoption. With careful planning and execution, biofortified crops have the potential to help the world effectively address malnutrition issues with minimal research investment. It is clear that biofortification has a lot of potential to raise the nutritional content of important crops. Recombinant DNA technology may be used to boost the bioavailability of several important vitamins and minerals. Since most people in underdeveloped nations live in rural areas, fortified food is not readily available or reasonably priced for them. By supplying the necessary technologies through the seeds of the main staple crops, biofortification can be very helpful in satisfying the nutrient needs of underprivileged communities at a reasonable cost. However, one of the major concerns is that very few biofortified transgenic crops have been commercialized for general cultivation. In order to reap the benefits of this technology, authorities must review various processes in order to eliminate any needless rules based on "precautionary" concepts.

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