Chapter 1
Introduction to Biofortification and Challenges for Nutrition Security

Asima Rasheed, Sabir Hussain, Muhammad Abdul Rehman Rashid, Ijaz Rasul, and Farrukh Azeem

Abstract By the middle of the century, the global population will have surpassed 9 billion people, increasing the demand for food, water, and space. Maintaining food security and sustainability presents several significant hurdles like nutritional deficits, postharvest losses, and inconsistent regulation. Micronutrient deficiency is one of the major concerns of the time that imparts negative health impacts on millions of people and is also referred to as "hidden hunger." To deal with the deficiency impacts, biofortification is presented as the most effective strategy that enhances the micronutrients in staple crops. This technique can also increase bioavailability by removing antinutrients from plants. The cultivars developed by biofortification are tagged as ideal for nutritional security which shows a positive response in vulnerable countries. The ability of biofortification to improve crop micronutrient levels has been demonstrated through research; the next step is effective execution and public consumption. Current chapter highlights various approaches for food biofortification and challenges related to food nutritional security.

1 Introduction

Food insecurity makes it more difficult for people to get the amount of food they need to meet their caloric needs. Due to the resulting deficiencies, a person may not be able to work properly or have enough strength to do daily duties, which also

A. Rasheed · M. A. R. Rashid · I. Rasul · F. Azeem (✉)
Department of Bioinformatics and Biotechnology, Government College University Faisalabad, Faisalabad, Pakistan
e-mail: farrukh@gcuf.edu.pk

S. Hussain
Department of Environmental Sciences, Government College University Faisalabad, Faisalabad, Pakistan

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lowers their ability and productivity to earn (Banerjee and Duflo 2011). The world population is expected to reach 9 billion people in 2050, which would bring numerous issues for the sustainability of food due to the rising demand for food. The economy of the target nation is also impacted by ongoing global population expansion in the absence of technological and environmental policy measures (Tian et al. 2016). A growing problem in the world's expanding population is malnutrition. Malnutrition affects 792.5 million people worldwide, with developing countries bearing the brunt of the problem. In underprivileged nations, the majority of people either go hungry or eat food that is lacking in nutrients. Almost, 24,000 people a day die from hunger-related causes worldwide. A third of the population on average is facing "hidden hunger." They lack one or more essential macronutrients or micronutrients in their diets, e.g., Zn, Fe, Se, I, folic acid, lysine, vitamin A, vitamin B12, vitamin C, and Vitamin D (Malik and Maqbool 2020). Vitamin A, iron, and zinc deficiencies are the three most typical nutritional deficiencies worldwide. In regions of the world such as Sub-Saharan Africa, the Caribbean, and East and West Asia, it is a significant public health issue (Siwela et al. 2020). Malnutrition and poverty have a crucial connection. Unstable and poor conditions brought on by poverty may exacerbate the malnutrition issue. People who live in poverty frequently experience financial constraints, which makes it difficult for them to obtain sufficient, wholesome meals (Peña and Bacallao 2002). Short-term micronutrient deficiency is harmless, but persistent deficiency can cause a variety of illnesses, including anemia (iron deficiency), beriberi (vitamin B deficiency), pellagra (niacin deficiency), rickets (vitamin D deficiency), and scurvy (vitamin C deficiency), some of which can be fatal (Ratajczak et al. 2021). To boost the nutrient output of farming systems, a variety of agricultural instruments (such as crop diversification, crop selection, fertilizers, cropping systems, soil amendments, etc.) could be used. The first agricultural strategy now being used to combat micronutrient deficiencies is biofortification (Bouis and Welch 2010).

As compared to other traditional approaches, biofortification is considered as most economical one due to its tremendous outcomes in short period. Even though initial investments are substantial, numerous researchers have already examined the cost-effectiveness of biofortification in numerous studies (Kumar and Pandey 2020). Because of its several advantages over food diversification and artificial food fortification, it has been demonstrated to be an effective strategy in many industrialized countries and produced germplasms can be shared internationally.

The first aim of this chapter is to highlight the challenges in nutrition security and food sustainability and, second, to highlight the different biofortification strategies for the development of improved and easily approachable foods while maintaining the food chain.

2 Current Challenges for Nutrient Security

A key problem at the moment is the need for more food and fiber sources to feed future generations. Various risks and constraints, some of which are addressed below, can severely limit the capacity to develop and maintain a sustainable global agri-food system to satisfy these demands.

2.1 Global Population

Food security is seriously threatened by the rise in global population, climate change, and the shrinking amount of arable land. The world population increased from 4.4 billion to 6.1 billion people between 1980 and 2000, and food production increased by 50% during that time. Since 2000, the global population has increased by about 2% per year, reaching 7.3 billion people in 2014. The global population is expected to increase to reach 9.7 billion people by 2050 (McCarthy et al. 2018). Increased population directly impacts the environment which in turn affects the production rate of food for people. This will happen directly by changing the land structure that is available and suitable for farming, as well as indirectly by preventing the formation of clouds that are driven by volatile organic compounds (Tian et al. 2016). The Food and Agriculture Organization (FAO) predicts that emerging countries' urbanized areas would see the majority of the world's population growth. It has also been shown that there is enough food production to feed the entire world's population, but due to socioeconomic hurdles, harsh environmental conditions, and a lack of social safety nets, this food supply cannot be spread equally throughout all continents, especially in developing countries (Sunderland et al. 2013). Hunger and malnutrition are two persistent problems in these emerging nations. More individuals are expected to experience inadequate nutrition as a result of the ongoing population growth, especially youngsters, making them more vulnerable to chronic illnesses and even mortality.

2.2 Climate Change

Climate change is defined as an increase in atmospheric temperature, increased carbon dioxide levels, and changes in precipitation. According to the FAO, these factors will all have an impact on agriculture and food production, leading to drought and more extreme temperature swings in many areas where food is produced. Accuracy and precision in estimating climate sensitivity are essential to any climate predictions (Franzke et al. 2015). It is the primary duty of the authorities dealing with food security to strictly consider and follow the predictions of climate. The ignorance of these predictions could impact the dimensions of food security (Burke et al. 2015). People being hungry or perhaps starving is a particular challenge faced by those projecting climate change's effects on the agri-food industry. It is possible to focus too much on some outcomes (such as the worst, most extreme temperature increases scenarios) and neglect to prepare and plan for a wider range of potential future climate trends. Furthermore, the established nonuniform regional climate trends that take place within an overall changing climate hinder the applicability of global climate change projections to food security. To accommodate for climatic changes in crop and nutritional policies and practices, regional decisions must be founded on research. This is crucial for ensuring global food security (Chandio et al. 2020). Extreme heat stress brought on by rising global temperatures can have a severe impact on crop yield. Crop yield and world food supply are predicted to suffer from projected changes in the frequency and intensity of extreme climatic events, especially at lower latitudes (Porter et al. 2014). More than just a risk, climate change is a challenge that calls for quick and decisive actions. To improve climate change mitigation and adaptation in developing countries, new approaches are required. Climate change is expected to have a significant impact on food costs, which will make goods unaffordable and heavily reliant on imports, particularly in developing nations (Arora 2019). One hundred and ninety-five nations adopted the first global climate pact to address climate change during the December 2015 United Nations Conference on Climate Change, which was held in Paris. The goal of this agreement was to keep global warming in the twenty-first century to less than 2 °C compared to preindustrial levels. According to estimates, the world's greenhouse gas emissions must fall by 40–70% by 2050 to achieve carbon neutrality, which would increase the sustainability of food production (Tian et al. 2016).

2.3 Water-Related Issue

Water being an essential need in agriculture, household activities, and other industrial infrastructures, is utilized extensively which results in a shortage of water around the globe. 1 kilogram of rice requires 3500 liters of water and 1 kg of beef needs 15,000 liters of water to produce, which are examples of the intense usage of water (Tian et al. 2016). Water use has increased at a rate that is more than twice as fast as population growth over the past century. Geographically, water is distributed unevenly throughout the world, and a lot of it is wasted, polluted, and handled in an unsustainable manner (Premanandh 2011). According to statistics, a quarter of global population faces water shortages, and the one-fifth population lives in areas with limited water resources. When climate change hits, two-thirds of the world's population would have insufficient access to clean water (Shan et al. 2020). Proper water management and greater access to fresh water are required to cope with the demands of food production and agricultural operations.

2.4 Postharvest Food Losses

Every year, around 1.3 billion tons of food have been wasted due to mishandling of whole supply chain, especially postharvest handling. In contrast, over 870 million people experience daily hunger, which accounts for more than one-third of the food produced globally. Food loss can also be taken place by using polluted water, which has additional financial expenses. Agricultural sector, food security, and food supply chain should be placed at the utmost priority in the development of ecologically friendly crop protection measures. To decrease food waste and postharvest losses, FAO developed a toolbox to give awareness among population on how to minimize and recycle trash (Tian et al. 2016). Large amounts are lost and squandered, which results in losses of not only food and nutrition but also of the natural resources utilized to manufacture and handle these goods, including land, water, chemicals, energy, and labor. Additionally, the losses and waste of agricultural products also have a great contribution to the development of environmental issues, such as the emission of greenhouse gases. Minimizing postharvest losses and wastes can only be an operative way to upsurge food availability in the food system, ensuing in shortened food insecurity, improved nutrition, improved income ratio, and reduced wasting of several resources such as land, water, chemicals, and energy (Yahia et al. 2019).

3 Application of Biofortification to Improve the Nutritional Profile of the Diet

For a long time, developing countries have focused to upgrade their agriculture-based research to develop improved and nutritious cereals. Besides the development in research, every third person is facing hidden hunger, which might be due to the hindrance in availability of mineral-based foods or foods with low quality. Recently, plant scientists have developed a new policy to produce varieties with an elaborated nutrient profile instead of focusing on increasing production rates to reduce hidden hunger (Christou and Twyman 2004). A sustainable and cost-effective process that enhances the nutrient ratio by adopting different techniques in the diet is called biofortification. Biofortified food may not provide as many micronutrients per day as fortified or commercially available foods, but they can provide an adequate daily intake of nutrients or vitamins throughout the individual's life (Riaz et al. 2020). Biofortification provides micronutrients or treats nutrient deficiencies more sustainably and cheaply to fewer resources community instead of eliminating malnutrition from their life. Once established, the biofortified crop system is extremely sustainable, even if government interest and finance for solving micronutrient issues wane, nutritionally enhanced seeds will continue to be planted and consumed for a longer time period (Saltzman et al. 2017). Furthermore, biofortification provides a feasible method of supplying naturally fortified meals to undernourished communities in relatively remote rural areas that have limited access to commercially marketed fortified foods, which are more easily accessible in urban areas (Singh et al. 2016). Many organizations have been working hard to eliminate malnutrition from the world and introduced many varieties of different crops into the markets By the end of 2016, more than 20 million people in 30 countries were eating biofortified crops, and 150 varieties of 10 crops were available (Jha and Warkentin 2020). Marketed surpluses of these crops may make their way into retail outlets, reaching consumers in first rural and then urban areas, in contrast to complementary interventions, such as fortification and supplementation, that begin in urban centers. Biofortification research is ongoing in the hope of minimizing or eradicating malnutrition caused by micronutrient deficiency. Biofortification research continues in the hope of reducing or eliminating malnutrition caused by micronutrient deficiency.

Many crops like wheat, maize, rice, and soybean, etc. are broadly consumed by the population that is unable to provide recommended daily doses of essential nutrients which in turn causes health issues. Biofortification successfully enhances Fe, Zn, Ca, Se, or different vitamins in highly consumed staple crops and grows improved crops for the population. Biofortification makes sure to enhance mineral absorption, their delivery to edible parts, and bioavailability. Many factors in crops require special attention to provide people with balanced diets (Kumar and Pandey 2020). The inadequacies that have drawn the attention of responsible authorities and governments for biofortification are briefly described in the section that follows.

3.1 Micronutrients

In basic foods, Fe, Zn, and vitamin A are the most deficient ones that are directly involved in the hidden hunger around the globe. The deficiency of these components causes anemia, color blindness, and bone diffraction and also affects mental development (Majumder et al. 2019). For humans, micronutrients are also considered important candidates as they work as cofactors of many functioning enzymes in the body that are involved in the metabolism and regulatory functions of the body. Wheat, rice, and maize are the primary sources of nutrients for people living in underdeveloped countries (Shahzad et al. 2021). Unfortunately, these agriculture-based foods contain deficient amounts of different nutrients especially Fe, Zn, and vitamin A which enable them to fulfill the daily nutrient requirements of the body and result in many major disorders in the body. Underaged children and pregnant women are the main targets of these deficiencies and about 40% population around the globe is labeled as anemic (Rempel et al. 2021). Wheat is the red meat of poor communities that must be biofortified with Fe, Zn selenium, iodine, vitamin, and other micronutrients for a healthy population. Maize is found with antioxidants, vitamin A and E (tocopherol) deficiencies that affect the quality of proteins in maize. The quality of zein proteins can be enhanced by increasing the concentration of tocopherol and lysin. As opposed to wild-typed lines of maize, varieties with opaque-2 (o2) mutant form maize have the potential to increase tocopherol and lysin content (Grover et al. 2020). Other crops like barley, sorghum chickpea pigeon pea, etc. are also deficient in essential micronutrients and required great attention to avoid hidden hunger.

3.2 Antinutrients

The chemical substances that exert harmful effects on human health by the reduction of nutrient absorption are labeled as antinutrients. These factors are mostly found in the edible part of crops. Within plant material, these substances have critical impacts on nutrients like minerals, vitamins, and proteins and their amount and intensity vary in each plant depending upon the chemical fertilizers used for growth purposes, method of propagation, as well as storage conditions, also affect their influence (Ugwu and Oranye 2006). Some major antinutrients are alkaloids, lectins, phytases, oxalates, and tannins. These substances are gifts to plants by nature for their defense against fungi, insects, and predators. The continued consumption of these compounds by the human population causes serious health issues as these substances interfere with the metabolic process which in turn reduces the bioavailability of essential nutrients (Sinha and Khare 2017). Some antinutrients are briefly discussed below.

Lectins Lectins are also known as phytohemagglutinins involved in the agglutination of red blood cells and have many active carbohydrates binding sites. These antinutrient substances are widely distributed in plants especially in grain products by nature, involved in the protection mechanism of plants (Mishra et al. 2019) but when these lectin-rich products are consumed by humans, several disorders like nausea, gastroenteritis, and diarrhea have caused. Some severe disorders such as destruction of the epithelial tissue of the gastrointestinal tract, local hemorrhage, and damage to the kidney, heart, or liver have also been reported by the toxicity of lectin (Vasconcelos and Oliveira 2004). Because lectins directly affect digestive enzymes, they decrease the digestibility of nutrients.

Phytase Phytases present in plants, animals, and soil are the salted form of phytic acid and are also known as Inositol hexakisphosphate (InsP6) (Desai et al. 2014). In monocotyledon plants, it can be removed easily during milling as it is present in the aleurone or bran layers. In dicotyledon plants, it is directly linked with the protein that can be removed along with phytase during processing and added adverse impacts on the nutritional value of the concerned food. Phytases are the storage house of phosphates and play important role in the germination of seeds and also serve as the energy house of plants (Gibson et al. 2018). Despite the beneficial role of phytates for plants, it is crucial for humans and animals because it forms complexes with Fe, Zn, Ca, and Mn in the digestive tract and lessens the bioavailability of these minerals (Schlemmer et al. 2009).

Tannins The plant kingdom also has one of the highest molecular weighted antinutrients named tannins and is involved in the defensive properties of plants. This type of antinutrient has chelated properties with Fe and Zn. Condensed tannins and hydrolyzable tannins are the two types of tannins. The first one is the ester of gallic acid while the second one is the polymer of polyhydroxy flavan-3-ol monomers and also known as proanthocyanidins (Balasundram et al. 2006). The tannin-rich foods are considered as least nutritious because these tannin compounds are responsible for a low growth rate, indigestibility of proteins, and lack of appetizers (Ozcan et al. 2014). According to Chung et al. (1998), tannins can contribute to the acceleration of esophageal and cheek cancers. However, some tannin molecules also contain antiviral, antifungal, and antioxidant (Pizzi 2019).

Saponins These are the widely distributed antinutrients mostly found in soybean, peanuts, spinach, broccoli, potatoes, apples and eggplants (Kregiel et al. 2017). The presence of a very low concentration of saponins in foods can build up soapy-nature constituents that can be distinguished by their bitter taste. Saponins are water-soluble agents with a major portion of nonsugary aglycone which term as sapogenin (Góral and Wojciechowski 2020). By the chemical nature of sapogenin, saponins are differentiated into steroidal and triterpenoid saponins. The minute concentration of saponins can decrease the absorption of glucose and cholesterol in the gut region via intraluminal physicochemical interaction and also destroy the red blood cells in the human body (Sinha and Khare 2017).

4 Biofortification Approaches

The basic goal of biofortification (Shahzad et al. 2021) can be achieved through three routes: conventional plant breeding, agronomic approach, and genetic engineering (Fig. 1.1). These routes of biofortification involved agriculturalists, economics, and nutritionists working together (Garcia-Casal et al. 2017) for the welfare of mankind by producing improved and safe staple crops like wheat, rice, maize, pulses, potato, sweet potato, tomatoes, etc. The three routes of biofortification are briefly described in the below section.

4.1 Agronomic Approach

The agronomic approach of biofortification uses fertilizer, soil, and beneficial microorganisms to enhance the nutrients of edible parts of plants (Philipo et al. 2021). This technique is economic and easy to temporally enrich the plants with nutrient contents. The adoption of this technique requires much knowledge about environmental factors as well as soil microorganisms. The accessibility, transmission, and consumption of nutrients by plant parts are the primary objectives of

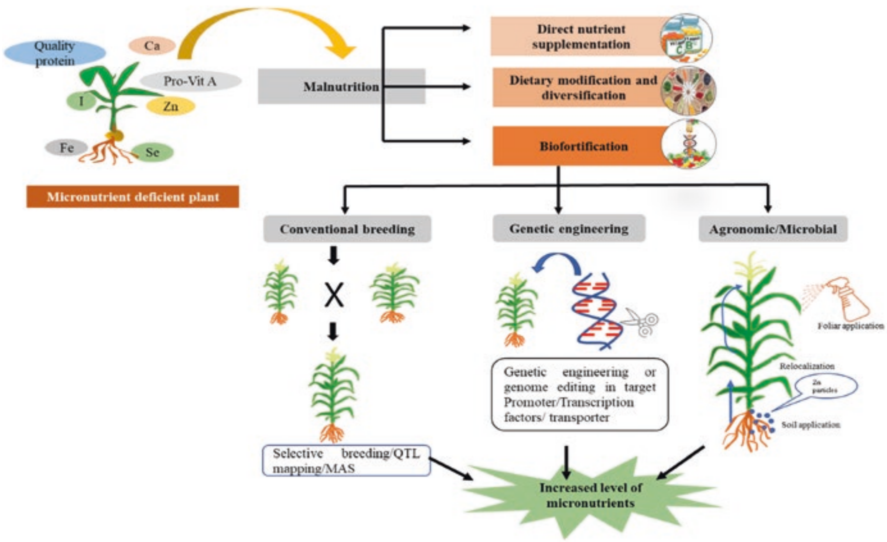

Fig. 1.1 Graphical representation of different biofortification approaches to overcome malnutrition. (Sourced from Sheoran et al. 2022)

agronomic biofortification (Shahzad et al. 2021). Naturally, the soil is rich with essential nutrients absorbed by the plants but sometimes plants are enabled to absorb nutrients and undergo nutrient deficiencies. In this condition, different nutrients are given to the oil. Nitrogen, phosphorus and potassium (NPK) are the frequently used nutrients in this approach (Rashid et al. 2020). Other than NPK, Zn and Fe are also reported as deficient the in the human diet, so these two are also applied under this approach to overcome their deficiencies. In China, a 75% increase in Zn content has been reported in wheat grain after Zn fertilizer application (Wang et al. 2016). Adequate attention related to environmental factors, ways of application and nature of nutrients required and adoption of an agronomic approach to biofortification. There are many options to enrich the plant nutrients under this strategy of biofortification. The target nutrient usually NPK can be directly added to the soil bed either during the preparation of soil for sowing or after the germination of plants. Thus, nutrients are taken up by plants and integrated into the food chain. Micronutrients in the liquid form are sprayed out on the aerial parts or on the reproductive parts of the plant that are absorbed by stomatal opening and resulted in healthier foods for consumers. Thirdly, micronutrients can also be flooded alongside irrigation that is absorbed by plants through root uptake and accumulated in edible parts of the plant (Shahzad et al. 2021). Several environmental factors like humidity, wind speed, temperature and time of application directly affect the efficiency of foliar and soil application. The moist or warm conditions of weather directly affect the permeability of plant tissues which in turn disturbs the efficiency of foliar and soil application. Before adopting these options for biofortification, sufficient research about the location and environmental conditions is necessary (De Valença et al. 2017).

Apart from benefits, the success of agronomic biofortification is directly dependent upon the transportation, and absorption of minerals among plant species. The soil composition of specific geographical areas also affects mineral deposition (Ismail et al. 2007). According to soil composition analysis, nearly half of India's agricultural soils, one-third of China's, 14 million hectares of Turkey, and eight million hectares of Australia are zinc deficient. The main disadvantage of agronomic biofortification is that the target nutrients accumulate in the plant's leaves or other inedible sections rather than in the fruits, grains, or other edible components (Garg et al. 2018). Furthermore, the presence of antinutrients in plants also hinders the bioavailability of target minerals in humans or animals. The greatest obstacle of all is the negative environmental effects of fertilizer deposition in soil and water (Waters and Sankaran 2011).

4.2 Conventional Plant Breeding Approaches for Biofortification

The main purpose of breeding activities is to enhance nutrient concentration to the target level in the edible parts of staple foods to ensure a healthy lifestyle for the population and to overcome malnutrition. In this method, plant breeders, nutritionists, and food technologists have collaborated to produce results that are long-lasting and sustainable while taking into consideration any gene screening or nutrient-related points (Kumar et al. 2022). Plant breeding not only focuses on improving the micronutrient content of edible plant parts but also takes into account how readily the body can absorb the targeted nutrients after cooking or preparation (Bouis and Welch 2010). Around the globe, several crops enriched with different nutrients have been developed and released under conventional plant breeding. Efficacy trials for vitamin A-rich OSP, provitamin A-fortified orange maize, provitamin A-fortified yellow cassava, iron pearl millet, and iron beans all provide promising evidence that biofortification improves micronutrient intake and deficiency status among target populations (Saltzman et al. 2017). To run fast and feasible breeding of plants with improved micronutrient and vitamins profile, the presence of adequate genotypic variation is mandatory. Parent lines with enhanced nutrient concentration are crossed with other lines several times to get a perfect product with desirable nutrients and agronomic traits. Contrary to agronomic biofortification, conventional breeding needed genetic diversity in the gene pool for the trait of interest (TOI). Sometimes, breeders need to cross lines with distant relative lines due to the limited genetic variations of TOI in the gene pool to get lines with the desired trait which slowly moved into commercial cultivars. Mutagenesis is another approach to transfer new traits into commercial varieties (Garg et al. 2018). Discovery of genetic differences that impact heritable mineral properties, evaluation of their stability under various situations, and determination of their breeding viability for higher mineral content in edible tissues without fluctuating yields or other quality attributes are some breeding approaches (Kaur et al. 2020). Traditional breeding depends on successful selection based on additive genetic effects, the heterosis phenomenon in F1 progeny, and transgressive segregation in later generations once a suitable genetic variation is available (Welch and Graham 2005). By lowering the amounts of antinutrients, the breeding strategy can be used to boost the bioavailability of nutrients. Antinutrients served as metabolites in plants and are directly related to plant metabolism and help out in biotic and abiotic resistance. The decrease in antinutrients required more precautions as it may impose negative impacts on crop health if not done carefully (Singh et al. 2016; Siwela et al. 2020). Since breeding programs are probably the quickest approach to improving plants, many international organizations have launched attempts to raise the nutritional content of crops. The European Union's Health Grain Project (2005–2010), funded with over £10 million and 44 partners from 15 countries, aimed to create high-quality cereal foods and components that promote good health. Numerous crops have been targeted for biofortification through crop breeding due to their improved acceptance (Bouis and Welch 2010).

Biofortification via conventional breeding also has several limitations. The major one is the limited genetic variations of traits in the gene pool of plants which might be solved by breeding with distant relatives but plant breeders also face difficulty to search for the gene of interest in distant relatives. This scenario makes it impossible for breeders to introduce crops with improved or desired traits through conventional breeding, e.g., Se improvement in wheat (Lyons et al. 2005) and oleic and linoleic acid improvement in soybean (Sarwar et al. 2020; Yeom et al. 2020). Moreover, only a small number of crops are enhanced through traditional biofortification, and the population grows solely dependent on these crops for greater nutrients, destroying the diversity of the environment and food. Diet diversification is crucial since some nutrients can be found in foods other than the basic crops that have been biofortified. Additionally, because existing biofortification solutions do not take into account the effects of "normal" meals on micronutrient deficits, they frequently fail over time (Lewis 2021).

4.3 Transgenic Approach

When agronomic and conventional breeding approaches fail to elevate the desired nutrient level in crops then transgenic biofortification becomes the only choice to plant scientists to enhance or introduce new nutrients in crops under limited or no genetic variation of traits in the plant's gene pool (Zhu et al. 2007). The transgenic modification approach can also be used to transfer genes of the desired trait from one species of plant to another which are unable to carry such genes naturally or when antinutrients present in a crop affect the uptake of nutrients (Jha and Warkentin 2020). It is also possible via a transgenic approach to introduce bacterial or other organisms' genes into crops to develop the desired trait or to explore pathways for metabolic engineering. The only key to developing a transgenic plant is the identification, characterization and utilization of the desired gene function (M. Vasconcelos et al. 2003). When a gene is identified and stamped as useful for a specific function, then it can be utilized in multiple crops under transgenic engineering biofortification and this is one of its major advantages over conventional breeding. For example, phytoene synthase (*PSY*), carotene desaturase, and nicotinamide synthase genes have been reported in many crops for essential mineral biofortification. By comparing the transgenic approach with breeding, the former proved as the most researched and emphasized one whereas later labeled as the most successful for commercial cultivar release (Garg et al. 2018). This approach has been broadly used on oilseeds biofortification due to the availability of limited genetic variation. Several crops such as golden rice with provitamin A, cassava with iron and vitamin A, and maize with high lysine content have been released as genetically modified crops (Vasconcelos et al. 2003).

There are also many barriers to the success rate of genetically modified crops for biofortification. The prominent one is that GM crops are not easily accepted by farmers, masses or communities (Vasconcelos et al. 2003). Secondly, it is an expensive approach that makes it beyond the access of poor people. Furthermore, extensive and detailed research regarding the identification, assessment and utilization of target genes is a time-consuming thing that lowers its success in terms of release. The other limitation is the poor regulatory and commercial releasing system of transgenic crops (Lewis 2021).

5 HarvestPlus Program

HarvestPlus program was launched with the contribution of CGIAR, International Center for Tropical Agriculture (CIAT), and International Food Policy Research Institute to develop nutrient-rich staple crops. The inputs of the HarvestPlus program along with agricultural and nutritional organizations to fight micronutrient deficiencies and hidden hunger are much appreciable around the globe. This program worked on strategies to control deficiencies among more vulnerable communities and to provide solutions based on food ingredients (La Frano et al. 2014). The World Health Organization (WHO) outlined Fe, Zn, and vitamin A as the three most underutilized micronutrients in the diet that require special attention. In this regard, the HarvestPlus Program plays a crucial and defined role in developing crop varieties rich in the aforementioned micronutrients by using practical, affordable methods like conventional breeding (Pfeiffer and McClafferty 2007). Currently, this program worked in Pakistan, India, Bangladesh, Nigeria, Rwanda, and Zimbabwe intending to provide nutrient-enriched foods to 1 billion people by 2030 (Bouis and Welch 2010). The main task of the HarvestPlus Program is to identify suitable nutrients to be biofortified because not all micronutrients are suitable for biofortification approaches due to their low concentrations or low absorption property in staple crops. Recently, maize (*Zea mays* L.), rice (*Oryza sativa* L.), wheat (*Triticum* spp.), beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz), sweet potatoes

(*Ipomoea batatas* L.), and pearl millet (*Pennisetum glaucum*) have been successfully biofortified by conventional breeding technique under this program (Ortiz-Monasterio et al. 2007).

HarvestPlus program comprises three phases: the discovery phase (2003–2008), the development phase (2009–2013), and the delivery phase (2014 onward). In the discovery phase, highly vulnerable populations, their dietary habits, resources, and studies were identified. In the development phase, the development of Fe, Zn, and vitamin A-rich crops in concerned countries, stability tests at several locations, and assessment of developed varieties in terms of nutrient ratio and planning to deliver them around the globe were all the aims focused by the researchers. Lastly, the establishment of consumer demand for biofortified crops to reach maximal populations was the main goal of the delivery phase. Researchers are engaged in estimating the area occupied by biofortified crops and working toward ensuring their long-term viability (La Frano et al. 2014). To date, the HarvestPlus program has released around 243 biofortified varieties of different crops in 30 countries. This single program has provided resources to nine million low-income farmers to grow developed varieties for the 42.4 million population (Shahzad et al. 2021).

6 Conclusion

It can be concluded that the use of both current and emerging technologies (coupled with the implementation of a wise policy) will be the most effective and long-lasting answer to issues with food security. The work of crop biofortification is difficult. The main objectives of many plant breeding efforts are to increase productivity, stress tolerance, food taste, and biotic and abiotic stress tolerance. Enhancing nutritional quality has been included as a new breeding objective in recent years. With the aid of regional, international, and domestic initiatives like the HarvestPlus program, this goal is being realized. To accomplish this goal, coordination between nutrition scientists and plant breeders is essential. Furthermore, because there is insufficient genetic variation for the micronutrients in the germplasm, several biofortification initiatives cannot be put into practice. Utilizing genetic engineering methods is necessary for these circumstances, and collaboration between molecular biologists and plant breeders is essential. Although there is more emphasis on transgenic methods, breeding-based approaches have much higher success rates because transgenically fortified crop plants must overcome barriers such as consumer acceptance issues and various pricey and time-consuming regulatory approval adopted by different countries. Despite these challenges, biofortified crops have a bright future since they have the potential to end micronutrient malnutrition among billions of poor people, especially in developing countries.

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