Journal of Medicinal Plants Studies
www.PlantsJournal.com

**ISSN (E): 2320-3862**
**ISSN (P): 2394-0530**
https://www.plantsjournal.com
JMPS 2022; 10(6): 63-69
© 2022 JMPS
Received: 20-09-2022
Accepted: 27-11-2022

**Rashmi Mathur**
Associate Professor, Department of Botany, Sri Aurobindo College, University of Delhi, Delhi, India

# Biofortification of crops to enhance nutritional values and quell hidden hunger

**Rashmi Mathur**

## Abstract

Biofortification represents an amalgamation of human ingenuity and scientific understanding, with an aim to address the global food shortage by making nutritious food more widely available for the betterment of humanity as a whole. Biofortification, also known as biological fortification, constitutes the procedure of boosting the dietary value or nutrient content of food through methods such as biotechnology, crop breeding, and fertilization. It is an endeavour to promote human health by increasing the concentration of vitamins, minerals, and other nutrients in food crops, thereby combating the prevalence of malnutrition. It is the process of selecting crops that are more profitable to farmers and consumers because they have better yields and beneficial micronutrient profiles when grown. This study evaluates several biofortification strategies for addressing the problems due to hidden or unrecognized hunger that may lead to varied and diverse kinds of chronic issues and diseases including osteoporosis, malignant cancer, neurological conditions, heart ailments, and numerous others. Biofortification is a viable option that is both cost-efficient and ecologically sustainable. The adoption of bio-fortified foods has greatly improved the immune system, boosting the ability to ward off potentially fatal pathogens. This article focuses on the promising potential offered by bio-fortified foods towards eradicating stifling hidden hunger.

**Keywords:** Agronomic biofortification, biotechnology, conventional crop breeding, dietary habits and health, environment, micronutrients, nutritional value, transgenic, well-being, yields.

## Introduction

Micronutrients are essential for human health. Biofortification is needed since many individuals in underdeveloped nations lack access to a variety of nutrient-rich meals and are malnourished (Olson *et al.*, 2021) [39]. This is particularly true for those whose staple food is rice, wheat, and maize every day. These crops lack vitamins and minerals, causing anaemia, stunted growth, and compromised immune systems (Lockyer, 2018) [34].

As the rate of climate change intensifies and the number of people around the world who are unable to afford appropriate health and nutrition increases, dietary diversification becomes increasingly important as a means of combating inadvertent starvation (Schnitter and Berry 2019). However, because people come from a wide range of socioeconomic backgrounds and the success of the implementation of a dietary diversification program depends on individuals' level of income, its benefits would not be seen for decades. Until then, biofortification aims to fulfil everyone's desire for health. Biofortification can solve the nutritional crisis, and improve vulnerable communities' health by enhancing the nutritional value of basic crops making a healthy and balanced diet more easily accessible. It can minimize nutritional deficits and related health issues by giving access to crops high in key nutrients that can improve community health and well-being. Biofortification can promote local agriculture by fostering regionally appropriate crop varieties. Biofortification is needed to increase nutrient-rich food access for vulnerable groups (Bouis, 2018) [8].

Three approaches — transgenic, agronomic, and conventional—are available for bio fortifying crops. The numerous plant varieties are screened by scientists to identify those that are rich in vital micronutrients such as iron, vitamin A, and zinc (Listman, 2019) [32]. These are then crossed with high-yielding cultivars. Crops with advantageous features such as early maturity, resistance to diseases and pests, and better yields are selected for their cost-effectiveness and sustainability, in addition to the additional nutrition provided by biofortification. In places like Africa, Asia, Latin America, and the Caribbean where these improved seed varieties are desperately required, they have become a shining new light of hope for local farmers.

**Corresponding Author:**
**Rashmi Mathur**
Associate Professor, Department of Botany, Sri Aurobindo College, University of Delhi, Delhi, India

Farmers in over 60 nations have used biofortification to enhance the nutritional standard of their families and communities (FAO, 2015) [19].

Biofortification can also be accomplished by the use of genetic engineering techniques, wherein gene expression pertaining to an increased iron intake in plants, can be modified, such as in rice, by activating genes that normally work only on a very low concentration of iron, but in this case are active throughout the plant's growth to increase its iron intake. Examples include golden rice, orange sweet potatoes, zinc beans, and zinc rice (Carvalho and Vasconcelos 2013) [12].

## Biofortified Crops

Biofortification is the science of cultivating crop plants to boost their nutritional content. Biofortified crops are those that have been nutritionally enhanced and have a higher bioavailability for the human population (Lockyer, 2018) [34]. Many Biofortified crops are already commercially available, and others are in various stages of research and development. Iron-rich rice, zinc-rich wheat, iron-rich beans, and zinc-rich sweet potatoes are just a few of the most well-known Biofortified staple crops grown in India and are easily accessible to the common man (Lockyer, 2018) [34].

The Indian government envisions Biofortified crops as an approach to boost people's dietary habits and health. In addition to investing in research and development of these crops, they have implemented policies to encourage their cultivation and consumption. Biofortification is a fundamental aspect of the government's plan to strengthen the population's nutritional well-being and tackle the issue of hidden hunger, caused by vitamin and mineral deficiencies that harm cognitive and physical development. Among disadvantaged populations, there is a delay in intervention because there are no apparent clinical signs or evaluations (Gödecke *et al.*, 2018) [24]. The present emphasis is on boosting the amount of nutrients consumed through meals. Regardless of receiving "enough to eat," individuals might not be consuming enough nourishment to meet their nutritional requirements (Bouis *et al.*, 2019; Lowe, 2021) [10, 35]. This as a consequence progressively ensues, the problem of concealed hunger (Beenish *et al.*, 2018) [21]. Bio-fortifying crops with micronutrients including iron, zinc, and vitamins A and C is the most popular method (Kumar, *et al.* 2019) [30].

The human body requires two kinds of nutrients - micronutrients and macronutrients. Macronutrients are the ones required in larger quantities than micronutrients but it doesn't imply that micronutrients are not as essential. Deficiencies of these micronutrients are a great cause of concern in the field of human healthcare (Shenkin A, 2006) [46]. Despite being required in minuscule quantities, micronutrient deficiency impairments can cause complications like cognitive disability, blindness, and death. Biofortification increases agricultural nutrition, improving individual and population health (WHO 2006) [54]. In India, where nearly half of all children are underweight and over a quarter are stunted, malnutrition is a serious issue. Rural communities, where nutritious food is scarce, are most affected. Biofortified crops may solve this problem by providing more nutritious food for children and adult. Nutrients can be added to the soil or increased in the plant. The idea is to help the plant absorb more of these nutrients from the soil so they may be incorporated into food (Elemike, 2019) [18].

Biofortification refers to the practice of boosting the dietary benefits of agricultural products through the use of either conventional breeding techniques or genetic engineering (Van Der Straeten *et al.*, 2020) [52]. The goal of biofortification is to increase the concentration of essential vitamins, minerals, and other nutrients in food crops to address nutritional deficiencies and improve human health (Van Der Straeten, *et al.*, 2020) [52]. Biofortification may solve micronutrient shortages, which afflict billions worldwide. The Indian government has prioritized nutrition in recent years. The Government has initiated numerous initiatives and schemes to address the issue of malnutrition across the country (Narayan, *et al.*, 2019) [38].

## Biofortification can be accomplished through several methods, including

Conventional breeding, wherein plants with desirable traits, such as higher nutrient content, are selected followed by cross-breeding them to create a new variety with the desired traits (Ahmar *et al.* 2020) [20].

Genetic engineering involves transgenically introducing new genes into the genome of a plant to improve its nutritional content (Kumar, *et al.* 2019) [30].

Agronomic practices involve modifying the way crops are grown, such as by using fertilizers or changing the soil pH, to improve the uptake and retention of nutrients (Elemike, 2019) [18].

## Benefits of Biofortification

Biofortification is a means by which human health as a whole can be enhanced (Bouis and Saltzman 2017) [9].

It provides a low-dose, food-based, sustainable alternative to medication (Agarwal *et al.*, 2020) [1].

Potential beneficiaries include rural residents and those living in poverty (Boy 2017) [11].

Many problems, including hunger and anaemia, can be solved using biofortification, a sustainable and economical solution (Van Der Straeten *et al.*, 2020) [52].

## Challenges of Biofortification

People are wary of consuming Biofortified foods like golden rice because of the colour modifications that take place in the grain (Gearing 2015; Hefferon 2015) [23, 26].

The initial costs also could be a barrier for people to implement this (Lockyer, 2018) [34].

Although micronutrients are required in minuscule quantities for normal physiologic functioning, their insufficiency can be particularly worrisome since it inevitably remains unrecognized in individuals for extended periods of time until symptoms emerge and manifest. For communities with severe nutrient deficiencies, bio fortification's fundamental drawback is that it cannot bring about a quick fix solution for people to regain a status of good health (Gani, *et al.* 2018) [21].

## Some of examples of transgenic crops are:

### Transgenic rice (*Oryza sativa*)

Vitamin A deficiency is a significant threat to public health in many third-world nations where people rely heavily on rice as a staple food. As a result of their limited financial resources, the poor often suffer from vitamin insufficiency. Golden Rice was first engineered in the late 1990s by a team of researchers from the Swiss Federal Institute of Technology and the University of Freiburg in Germany. The development of golden rice, a genetically engineered source of the provitamin A beta carotene, represents a major step forward in the effort to alleviate human illness through biotechnology, as The Golden Rice is a GM strain of the grain that generates beta-carotene—a precursor of vitamin A in the human body. Beta-carotene is a precursor to vitamin A, and a genetically engineered strain of rice has been created to have greater quantities of this compound (Tang, *et al.* 2009) [48]. The rice was genetically manipulated to synthesize beta-carotene within the rice endosperm, the edible part of the rice grain. This was achieved by introducing genes from a daffodil and a soil bacterium *(Bascillus thurengensis*) into the rice genome (Beyer *et al.*, 2002) [7]. Thereby making it a potentially more sustainable and cost-effective source of vitamin A for people who rely heavily on rice as a staple food, as opposed to other conventional rice varieties or other interventions, such as vitamin A supplements or fortified foods, which can be expensive and require ongoing investment. Golden Rice can be grown as well as distributed locally at a low cost. It can be cultivated in areas where other sources of vitamin A are not available or affordable, making it a potentially valuable tool for improving the health and well-being of vulnerable populations in developing countries. It is a sustainable approach to addressing vitamin A deficiency because it is contingent upon natural biological processes as opposed to synthetic supplements or fortified foods (Tang, *et al.* 2009) [48]. The Golden rice has undergone extensive testing for potential allergen city and toxicity for human consumption, as well as for potential environmental impacts such as gene flow to wild rice populations, to ensure that it is safe to be eaten and is also safe for the environment (Dubock 2014) [14].

Golden Rice has however been the subject of much controversy and debate, with critics raising concerns about the safety of genetically modified organisms (GMOs) and the potential environmental and health risks associated with their use (Dubock 2014) [14]. Supporters of the genetically modified Golden Rice argue that it has the innate capability to elevate the nutritional situation of millions of people, particularly in underdeveloped nations where vitamin A shortfall is a major public health challenge (Tang, *et al.* 2009) [48].

While Golden Rice offers potential advantages in addressing Vitamin A deficiency, it also has some potential disadvantages, in terms of a limited impact. Although it is a promising intervention for addressing vitamin A deficiency, it may not be adequate to completely solve the problem. Other interventions, such as improved dietary diversity and access to vitamin A supplements, may also be necessary. Another pressing issue with Golden Rice is the fact that it is a genetically modified organism (GMO), which has raised concerns about the safety and environmental impact of GMOs. Some critics argue that GMOs may have unintended consequences, such as the development of resistance to pests or the contamination of non-GMO crops (Dubock, 2019) [16]. Furthermore, Golden Rice is owned by a private company, which has raised concerns about intellectual property rights and access to the technology (Kowalski & Kryder 2002). Critics argue that this could limit the ability of small farmers and vulnerable populations to access the benefits of the technology. The approval process for Golden Rice has been lengthy and expensive, which could limit its adoption and distribution in some nations. The introduction of Golden Rice may face social and cultural challenges, particularly in areas where rice is considered a traditional and culturally important crop. Some people may be resistant to adopting a new variety of rice, particularly if it is perceived as being "unnatural" or a product of Western science (Dubock, 2017) [15].

### Transgenic Wheat

(*Triticum aestivum*) is cultivated in many countries as a predominant food crop. Scientists have been striving to boost antioxidant efficiency while simultaneously addressing widespread deficiencies in essential minerals, amino acids and micronutrients, for managing the challenges of overeating and obesity (Phougat and Sethi 2019; Gaikwad *et al.*, 2020) [41, 20].

### Transgenic Potato

(*Solanum tuberosum*) ranks as the 4th most significant dietary component that provides calories worldwide. With the objective of enhancing ascorbic acid production in potatoes, the strawberry GaIUR gene has been overexpressed. Goals of modification include the production of transgenic potato strains that produce less reducing sugars (Del Mar Martínez-Prada, *et al.*, 2021) [13].

### Transgenic Mustard

*(Brassica juncea)* is an invaluable commercial plant that is cultivated for its oil. Modifications are aimed towards developing a variety with increased levels of beneficial unsaturated fatty acids (Gaikwad, *et al.*, 2020) [20].

### Biofortification to overcome zinc deficiency

The health of a population depends on access to safe, nutritious food. Human health is significantly impacted by issues like food insecurity, an unbalanced diet, eating food grains with low nutritional value, eating the same things over and over again, etc. In fact, the quality of one's diet may decline even more due to food and nutritional insufficiency, heightening the risk of both under nutrition and obesity. Micronutrient absorption and dietary diversity have both declined as a result of the rise in the growth of cereal crops and cash crops in intensive cropping systems. Most people in rural parts of poor countries rely heavily on cereal as a staple food. Farmers were able to turn a profit after the green revolution brought input-responsive and high-performing varieties of staple crops like wheat and rice. As a result, farmers shifted their attention to more lucrative cereal crops at the expense of pulses (Dwivedi *et al.*, 2017) [17].

Despite the fact that humans have cultivated more than 7,000 different species, only 30 of those species account for over 95% of the world's energy supply. Finding a way to ensure food and nutritional security is crucial, especially in developing countries. 840 million people will be hungry by 2030 if the current trend continues. There is a strong correlation between socioeconomic status and food choices (Alkerwi *et al.*, 2015) [3].

The deficiency of zinc is studied to be the main reason why land and water productivity of rice and wheat yield has been decreasing in countries like South Asia. Biofortification is a method for boosting the levels of Zn in crops, which can help alleviate zinc insufficiency.

Zinc (Zn) is an example of a micronutrient, of which about thirty per cent of the global populace is deficient. Zinc deficiency has been linked to stunting, diarrhoea, and pneumonia (severe in children, being the leading reason for infant mortality); (Gupta *et al.*, 2020; Lassi *et al.*, 2020) [20, 31].

Zinc deficiency can be overcome by increasing the amount of Zn in crops by Biofortification. The intake of zinc in diet can be improved by agronomic as well as by transgenic means (Garg *et al.*, 2018) [22]. Agronomically, Zn can be increased by using Zn-based biofertilizers on crops or by increasing phyto availability of Zn in soil by use of adequate crop rotation patterns, the introduction of appropriate microbes, and enhancement of the alkalinity of the soil. In regions where fertilizers composed of minerals are often employed to boost nutrient and mineral count in crops, agronomic biofortification of Zn has proven to be effective (Ramesh *et al.*, 2014) [43]. Some commonly used Zinc fertilizers are ZnSO4, ZnO, and synthetic zinc chelates. These biofertilizers are introduced to the crops and are then absorbed by the apoplast of the leaves and finally taken in by the plant cells. Transgenic or Genetic biofortification includes increasing the Zn amount in the plant parts suitable for consumption (Elemike, 2019) [18]. Genetic means can only come into use if there is enough amount of zinc present in the soil for the plants to absorb it.

The introduction of bZIP19 and bZIP23 genes can be used to augment the build-up of zinc in consumable plant portions of the crops (Assunção *et al.*, 2010) [4]. The specific targets for enhancement of Zinc concentration in roots are the transport proteins of the plasma membrane and tonoplast of cells whereas some important targets for shoot enhancement include: enzymes associated with the formation of compounds facilitating zinc movements in xylem, tonoplast of shoot cells as well as enzymes catalyzing the synthesis of compounds responsible for detoxification of Zn ions in and out of shoot cells. *Arabidopsis thaliana* has been experimented with to be successful in the genetic biofortification of zinc.

Even though zinc biofortification has been helpful in overcoming zinc deficiency to some extent and is also very practical and cost-effective as compared to the fortification of other minerals in crops, it still remains one of the least explored techniques and hasn't been as helpful as it could be if explored more genetically in the study of the appropriate biomarkers required. In order to advance and take a step further in zinc biofortification, cutting-edge research should (i) improve agricultural and biological techniques to study targets of phloem-fed tissues and their mineral enhancement, (ii) identification of processes that influence Zn equilibrium in plant cells and methods for controlling cytoplasmic zinc levels.

## Some other examples of Biofortified crops include

**Orange Sweet Potato:** A variety of sweet potatoes that have been bred to contain higher levels of beta-carotene, which is converted to vitamin A in the body (Van Jaarsveld *et al.*, 2005) [53].

**High-Lysine Maize:** A variety of maize that has been bred to contain higher levels of the amino acid lysine, which is important for the development and growth of humans (Liu *et al.*, 2016) [33].

**Vitamin A Cassava:** Cassava is an essential source of nutrition in many parts of Africa, but it is low in vitamin A. Vitamin A cassava has been genetically modified to produce higher levels of beta-carotene, a precursor to vitamin A, which can help to minimize vitamin A deficiency in individuals who depend upon cassava as a primary source of food (Beyene *et al.*, 2018) [6].

High-protein maize is a variety of maize that has been bred to contain higher levels of protein. This can help to address protein deficiency, which is a common problem in many developing countries (Prasanna *et al.*, 2020) [42].

Soybeans with increased amounts of vitamin E were created through genetic modification since Vitamin E is an important antioxidant that can aid in thwarting persistent medical conditions like cancer and cardiovascular diseases (Kramer *et al.*, 2014; Rizvi *et al.*, 2014) [29, 44].

Iron Beans are a variety of common beans that have been bred to contain higher levels of iron. Deficit of iron is a widespread phenomenon in many underdeveloped nations, particularly among women and children (as they are at a higher risk of iron deficiency due to increased iron requirements during pregnancy and growth), and iron beans offer a sustainable and affordable way to address this problem (Beebe, 2020) [5]. Iron beans were developed through conventional breeding methods, which involved selecting beans with higher iron content and cross-breeding them to create new varieties with even higher iron content. The resulting iron beans contain up to 50% more iron than traditional bean varieties (Tavares Antunes *et al.*, 2019) [49]. They are an important source of iron for populations that rely heavily on beans as a primary source of protein. Iron beans are also easy to grow, using traditional farming methods and can be preserved for a considerable amount of time without spoilage, making them a practical and sustainable intervention for addressing iron deficiency in developing countries (Petry *et al.*, 2015) [40]. Iron Beans are accessible to rural and remote communities where iron-rich foods are not easily available or affordable, thereby helping to strengthen the dietary requirements and general well-being of disadvantaged groups of people, particularly women and children who are at high risk of iron deficiency. Moreover, Iron Beans are a hardy crop that can grow in a variety of conditions, including areas with low soil fertility. This can help to increase agricultural productivity in areas where traditional crops struggle to grow.

However, there are a few potential concerns pertaining to Biofortified Iron Beans, including their reduced genetic diversity because the process of breeding Iron Beans for a higher iron content may lead to a reduction in genetic diversity, making the crop more vulnerable to pests and diseases (Petry *et al.*, 2015) [40]. Some consumers may be hesitant to adopt new varieties of beans, particularly if they are unfamiliar with the taste or cooking methods. As with any new crop variety, there is a risk of unintended consequences, such as unintended effects on the environment or unintended health effects. There may be some additional costs associated with developing and distributing Biofortified Iron Beans, although these costs may be offset by the potential health and economic benefits (Vaiknoras *et al.*, 2019) [51]. Moreover, if Iron Beans become the primary source of iron for vulnerable populations, there is a risk of dependence on a single crop variety. This could be a concern if a pest or disease outbreak were to affect the crop (Malhi *et al.*, 2021) [37].

The worldwide challenge of deficient iron levels and anaemia has been specifically singled out for rice as a potential solution. By the process of selective breeding, a variety of rice containing higher levels of zinc has been developed to counter zinc deficiency, which is a common problem in many developing countries, particularly among children. Zinc rice offers a sustainable and affordable way to address this problem (Singh *et al.*, 2017; Majumder *et al.*, 2019) [47, 36].

## Conclusions

People experience "hidden hunger" when their caloric intake is adequate but they are not getting enough of the nutrients that are required for healthy growth and development. By breeding or genetically modifying crops to contain higher levels of key nutrients, biofortification can help to strengthen the nutritional status and overall health of masses all over the world. Biofortified crops can potentially enhance nutritional status, and reduce the incidence of nutrient deficiencies and associated health issues of vulnerable populations in underdeveloped nations that rely significantly on staple foods crops for their daily diet. However, it is essential that biofortification be conducted in a safe and sustainable manner, with appropriate regulation and testing to ensure the safety of the environment and human health. Specific targeted population groups are receiving micronutrients through Biofortified food crops, including grains, legumes, vegetables, and fruits. While transgenic research is receiving more funding and attention, the success rate and social acceptability of breeding remain substantially higher. Despite these obstacles, Biofortified crops have a promising future in helping to solve the problem of hunger.

There are three primary impediments to accomplishing the goal of making biofortification a reality for one billion individuals by 2030: 1) incorporating it into governmental agricultural research initiatives; 2) strengthening consumption amongst consumers; and 3) encompassing it into public and corporate initiatives, and investments. Many steps have been taken towards the goal, but sustained progress toward this lofty objective requires the backing of authoritative institutions.

## References

1. Agarwal N, Upadhyay, Tigadi B. Biofortification to improve nutrition: A review. International Journal of Current Microbiology and Applied Sciences. 2020;9(1):763-779. https://doi.org/10.20546/ijcmas.2020.901.083
2. Ahmar S, Gill RA, Jung KH, Faheem A, Qasim MU, Mubeen M, Zhou W. Conventional and Molecular Techniques from Simple Breeding to Speed Breeding in Crop Plants: Recent Advances and Future Outlook. International Journal of Molecular Sciences. 2020;21(7):2590. https://doi.org/10.3390/ijms21072590
3. Alkerwi A, Vernier C, Sauvageot N, Crichton GE, Elias MF. Demographic and socioeconomic disparity in nutrition: application of a novel Correlated Component Regression approach. BMJ Open. 2015;5(5):e006814. https://doi.org/10.1136/bmjopen-2014-006814
4. Assunção AG, Herrero E, Lin YF, Huettel B, Talukdar S, Smaczniak C, *et al.* Arabidopsis thaliana transcription factors bZIP19 and bZIP23 regulate the adaptation to zinc deficiency. Proceedings of the National Academy of Sciences of the United States of America. 2010;107(22):1029610301. https://doi.org/10.1073/pnas.1004788107
5. Beebe S Biofortification of Common Bean for Higher Iron Concentration. Front. Sustain. Food Syst. 2020;4:573449. DOI: 10.3389/fsufs.2020.573449
6. Beyene G, Solomon FR, Chauhan RD, Gaitán-Solis E, Narayanan N, Gehan J, *et al.* Provitamin A biofortification of cassava enhances shelf life but reduces dry matter content of storage roots due to altered carbon partitioning into starch. Plant biotechnology Journal. 2018;16(6):1186-1200. https://doi.org/10.1111/pbi.12862
7. Beyer P, Al-Babili S, Ye X, Lucca P, Schaub P, Welsch R, Potrykus I. Golden Rice: introducing the beta-carotene biosynthesis pathway into rice endosperm by genetic engineering to defeat vitamin A deficiency. The Journal of Nutrition. 2002;132(3):506S-510S. https://doi.org/10.1093/jn/132.3.506S
8. Bouis H. Reducing mineral and vitamin deficiencies through biofortification: progress under HarvestPlus. In Hidden hunger: Strategies to improve nutrition quality. Karger Publishers. 2018;118:112-122.
9. Bouis HE, Saltzman A. Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. Global food security. 2017;12:49-58. https://doi.org/10.1016/j.gfs.2017.01.009
10. Bouis H, Saltzman A, Birol E. Improving nutrition through biofortification. In: Shenggen F, Sivan Y, Rajul PL. Editors. Agriculture for Improved Nutrition: Seizing the Momentum. Wallingford: International Food Policy Research Institute; c2019. p. 47-57. https://doi.org/10.1079/9781786399311.0047
11. Boy E. Biofortification: Helping meet nutrition needs worldwide. Field Exchange. Available at; c2017. https://www.ennonline.net/fex/53/biofortification.
12. Carvalho SMP, Vasconcelos MW. Producing more with less: strategies and novel technologies for plant-based food biofortification. FRIN. 2013;54:961-71. 10.1016/j.foodres.2012.12.021 https://doi.org/10.1016/j.foodres.2012.12.02
13. Del Mar Martínez-Prada M, Curtin SJ, Gutiérrez-González JJ. Potato improvement through genetic engineering. GM Crops & Food. 2021;12(1):479-496. https://doi.org/10.1080/21645698.2021.1993688
14. Dubock A. The politics of Golden Rice. GM crops & Food. 2014;5(3):210-222. https://doi.org/10.4161/21645698.2014.967570
15. Dubock A. Golden Rice: instructions for use. Agric & Food Secur. 2017;6:60. https://doi.org/10.1186/s40066-017-0136-2
16. Dubock A. Golden Rice: To Combat Vitamin A Deficiency for Public Health. Intech Open; c2019. DOI: 10.5772/intechopen.84445
17. Dwivedi SL, Lammerts Van Bueren ET, Ceccarelli S, Grando S, Upadhyaya HD, Ortiz R. Diversifying Food Systems in the Pursuit of Sustainable Food Production and Healthy Diets. Trends in Plant Science. 2017;22(10):842-856. https://doi.org/10.1016/j.tplants.2017.06.011
18. Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO. The Role of Nanotechnology in the Fortification of Plant Nutrients and Improvement of Crop Production. Applied Sciences. 2019;9(3):499. https://doi.org/10.3390/app9030499
19. FAO. Food and Agriculture Organization FAO; International Fund for Agricultural Development IFAD; World Food Programme WFP. The State of Food Insecurity in the World 2015; Food and Agriculture Organization of the United Nations: Rome, Italy; c2015.
20. Gaikwad KB, Rani S, Kumar M, Gupta V, Babu PH, Bainsla NK, *et al.* Enhancing the Nutritional Quality of Major Food Crops Through Conventional and Genomics-Assisted Breeding. Front. Nutr. 2020;7:533453. https://doi.org/10.3389/fnut.2020.533453
21. Gani G, Beenish, Bashir O, Bhat TA, Naseer B, Qadri T, *et al.* Hidden hunger and its prevention by food processing: A review. International Journal of Unani and Integrative Medicine. 2018;2(3):01-10. Available at: Hidden_hunger_and_its_prevention_by_food.
22. Garg M, Sharma N, Sharma S, Kapoor P, Kumar A, Chunduri V, Arora P. Biofortified Crops Generated by Breeding, Agronomy, and Transgenic Approaches Are Improving Lives of Millions of People around the World. Frontiers in Nutrition. 2018;5:12. https://doi.org/10.3389/fnut.2018.00012
23. Gearing ME. Good as Gold: Can Golden Rice and Other

Biofortified Crops Prevent Malnutrition?; c2015 Available at: https://sitn.hms.harvard.edu/flash/2015/good-as-gold-can-golden-rice-and-other-biofortified-crops-prevent-malnutrition/

24. Gödecke T, Stein AJ, Qaim M. The global burden of chronic and hidden hunger: Trends and determinants. Global food security. 2018;17:21-29. https://doi.org/10.1016/j.gfs.2018.03.004
25. Gupta S, Brazier AKM, Lowe NM. Zinc deficiency in low- and middle-income countries: Prevalence and approaches for mitigation. J Hum Nutr Diet. 2020;33: 624-643. https://doi.org/10.1111/jhn.12791
26. Hefferon KL. Nutritionally enhanced food crops; progress and perspectives. International Journal of Molecular Sciences. 2015;16(2):3895-3914. https://doi.org/10.3390/ijms16023895
27. Herrera-Estrella L, Alvarez-Morales A. Genetically modified crops: hope for developing countries? The current GM debate widely ignores the specific problems of farmers and consumers in the developing world. EMBO Reports. 2015;2(4):256-258. https://doi.org/10.1093/embo-reports/kve075
28. Kowalski SP, Kryder RD. Golden Rice: A Case Study in Intellectual Property Management and International Capacity Building, 13 RISK 47; c2002.
29. Kramer CM, Launis KL, Traber MG, Ward DP. Vitamin E levels in soybean (Glycine max (L.) Merr.) Expressing a p-hydroxyphenylpyruvate gene from oat (Avena sativa L.). Journal of Agricultural and Food Chemistry. 2014;62(15):3453-3457. https://doi.org/10.1021/jf4048995
30. Kumar S, Palve A, Joshi C, Srivastava RK, Rukhsar. Crop biofortification for iron (Fe), zinc (Zn) and vitamin A with transgenic approaches. Heliyon. 2019;5(6): e01914. https://doi.org/10.1016/j.heliyon.2019.e01914
31. Lassi ZS, Kurji J, Oliveira CS, Moin A, Bhutta ZA. Zinc supplementation for the promotion of growth and prevention of infections in infants less than six months of age. The Cochrane database of systematic reviews. 2020;4(4):CD010205. https://doi.org/10.1002/14651858.CD010205.pub2
32. Listman GM, Guzmán C, Palacios-Rojas N, Pfeiffer WH, Vicente FS, Govindan V. Improving nutrition through biofortification: preharvest and postharvest technologies. Cereal Foods World. 2019;64(3):39. ISSN: 0146-6283; DOI: 10.1094/CFW-64-3-0025
33. Liu X, Zhang C, Wang X, Liu Q, Yuan D, Pan G, *et al.* Development of high-lysine rice via endosperm-specific expression of a foreign Lysine Rich Protein gene. BMC Plant Biol. 2016;16:147. https://doi.org/10.1186/s12870-016-0837-x
34. Lockyer S, White A, Buttriss JL. Bio fortified crops for tackling micronutrient deficiencies – what impact are these having in developing countries and could they be of relevance within Europe?. Nutr Bull. 2018;43:319-357. https://doi.org/10.1111/nbu.12347
35. Lowe NM. The global challenge of hidden hunger: perspectives from the field. Proc Nutr Soc. 2021;80:283-289. https://doi.org/10.1017/S0029665121000902
36. Majumder S, Datta K, Datta SK. Rice Biofortification: High Iron, Zinc, and Vitamin-A to Fight against “Hidden Hunger”. Agronomy. 2019;9(12):803. https://doi.org/10.3390/agronomy9120803
37. Malhi GS, Kaur M, Kaushik P. Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. Sustainability. 2021;13(3):1318. https://doi.org/10.3390/su13031318
38. Narayan J, John D, Ramadas N. Malnutrition in India: status and government initiatives. Journal of Public Health Policy. 2019;40(1):126-141. https://www.jstor.org/stable/48703435.
39. Olson R, Gavin-Smith B, Ferraboschi C, Kraemer K. Food Fortification: The Advantages, Disadvantages and Lessons from Sight and Life Programs. Nutrients. 2021;13(4):1118. https://doi.org/10.3390/nu13041118
40. Petry N, Boy E, Wirth JP, Hurrell RF. Review: The potential of the common bean (Phaseolus vulgaris) as a vehicle for iron biofortification. Nutrients. 2015;7(2):1144-1173. https://doi.org/10.3390/nu7021144
41. Phougat D, Sethi SK. Wheat Biofortification: Agricultural investment to refrain malnutrition especially in developing world. Journal of Entomology and Zoology Studies. 2019;7(4):506-510
42. Prasanna BM, Palacios-Rojas N, Hossain F, Muthusamy V, Menkir A, Dhliwayo T, *et al.*. Molecular Breeding for Nutritionally Enriched Maize: Status and Prospects. Frontiers in genetics. 2020;10:1392. https://doi.org/10.3389/fgene.2019.01392
43. Ramesh A, Sharma SK, Sharma MP, Yadav N, Joshi OP. Inoculation of zinc solubilizing Bacillus aryabhattai strains for improved growth, mobilization and biofortification of zinc in soybean and wheat cultivated in Vertisols of central India. Applied Soil Ecology. 2014;73:87-96. ISSN: 0929-1393. https://doi.org/10.1016/j.apsoil.2013.08.009
44. Rizvi S, Raza ST, Ahmed F, Ahmad A, Abbas S, Mahdi F. The role of vitamin e in human health and some diseases. Sultan Qaboos University Medical Journal. 2014;14(2):e157-e165.
45. Schnitter R, Berry P. The Climate Change, Food Security and Human Health Nexus in Canada: A Framework to Protect Population Health. International Journal of Environmental Research and Public Health. 2019;16(14):2531. https://doi.org/10.3390/ijerph16142531
46. Shenkin A. Micronutrients in health and disease. Postgraduate Medical Journal. 2006;82(971):559-567. https://doi.org/10.1136/pgmj.2006.047670
47. Singh SP, Gruissem W, Bhullar NK. Single genetic locus improvement of iron, zinc and β-carotene content in rice grains. Scientific Reports. 2017;7(1):6883. https://doi.org/10.1038/s41598-017-07198-5
48. Tang G, Qin J, Dolnikowski GG, Russell RM, Grusak MA. Golden Rice is an effective source of vitamin A. The American Journal of Clinical Nutrition. 2009;89(6):1776-1783. https://doi.org/10.3945/ajcn.2008.27119
49. Tavares Antunes P, Vaz-Tostes MdG, Tomáz Sant’Ana C, Araújo de Faria R, Lopes Toledo RC, *et al.* Bioavailability of Iron and the Influence of Vitamin A in Biofortified Foods. Agronomy. 2019;9(12):777. https://doi.org/10.3390/agronomy9120777
50. UNICEF. Child Stunting, Hidden Hunger and Human Capital in South Asia: Implications for Sustainable Development Post; c2015. Available at: https://www.unicef.org
51. Vaiknoras K, Larochelle C, Birol E, Asare-Marfo D, Herrington C. Promoting rapid and sustained adoption of biofortified crops: What we learned from iron-

biofortified bean delivery approaches in Rwanda. Food Policy. 2019;83:271-284. https://doi.org/10.1016/j.foodpol.2018.11.003

52. Van Der Straeten D, Bhullar NK, De Steur H, Gruissem W, MacKenzie D, Pfeiffer W, *et al.* Multiplying the efficiency and impact of biofortification through metabolic engineering. Nature Communications. 2020;11(1):5203. https://doi.org/10.1038/s41467-020-19020-4
53. Van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Ambrose J Spinnler Benadé. B-Carotene–rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test, The American Journal of Clinical Nutrition. 2005;81(5):1080-1087. https://doi.org/10.1093/ajcn/81.5.1080
54. WHO. Guidelines on food fortification with micro-nutrients. World Health Organization; c c2006. https://apps.who.int › handle › 9241594012_eng