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Enhancing nutritional value in fruit crops through biofortification: A comprehensive review

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ABSTRACT

Achieving the UN Sustainable Development Goal 2 (UN-SDG2) of eradicating all forms of hunger by 2030 is a formidable yet imperative challenge, given the constrained timeline and the adverse global repercussions of hunger on health and socio-economics. Approximately one-third of the global population suffers from malnutrition or hidden hunger due to micronutrient deficiencies, posing a severe hindrance to economic progress. This has prompted numerous nations to create solutions that could aid in the fight against malnutrition and covert hunger. Food supplementation and dietary diversity are two interventions that are being used. However, the most effective fortification, particularly biofortification, has been predicted to lasting remedy for unmet hunger and malnutrition. To address this issue, the strategy of fruit crop biofortification through gene stacking, employing a judicious blend of traditional breeding and metabolic engineering techniques, holds the potential for significant progress in the next decade. To realize this goal, several specific actions and policy measures are recommended. These measures are vital in our collective pursuit of ending hunger, enhancing global health, and fostering economic development by 2030 as outlined in UN-SDG2. This review article highlights recent research findings and the progress made in expanding biofortification to new countries and environments, thus addressing the global challenge of malnutrition.

Keywords: Biofortification, Fruit crops, Hidden hunger, Malnutrition

The global challenges of increasing population, inadequate nutrition, and hunger pose significant challenges for development of many countries worldwide. One of the major public health concerns associated with these challenges is the deficiency of essential vitamins and minerals (Anonymous 2019). Among these, vitamin A deficiency (VAD) is particularly prevalent in developing nations, leading to over 600,000 deaths annually, with children under the age of 5 being the most affected group (Anonymous 2021). The NFHS-5 made some significant findings in relation to child nutrition. At 46.5% and 42.9%, respectively, Meghalaya and Bihar have the highest rates of stunted children. The greatest rate of wasted children was seen in Maharashtra (25.6%), with Gujarat following behind at 25.1%. In addition, Jharkhand had the largest percentage of women with below-normal Body Mass Index (BMI), at 26%, among those aged 15 to 49 (Anonymous 2022). These deficiencies contribute to various health issues and physical disorders among individuals. With the goal of improving the nutritional quality of food crops, biofortification focuses on enhancing the levels of essential vitamins and minerals in edible plant parts. In recent years, considerable attention has been given to biofortification in fruit crops due to their widespread consumption and well-recognized health benefits. On the other hand, modern biotechnological approaches, such as genetic engineering, gene editing and marker-assisted selection, enable more targeted and rapid improvements in nutrient content (Moose and Mumm 2008). Several key micronutrients have been targeted for biofortification in fruit crops, including vitamin C, pro-vitamin A carotenoids (such as beta-carotene), vitamin E, iron and zinc (Bakshi *et al*. 2013a and 2013b). In this review article, we will explore the progress made in biofortification of fruit crops and its potential impact on global health. We will examine the different strategies employed for enhancing nutrient content, the challenges faced during biofortification efforts, and the potential implications for addressing malnutrition. Moreover, we will discuss the acceptability, safety and regulatory considerations associated with biofortified fruit crops. This review aims to provide a comprehensive overview of the current state of biofortification in fruit crops, highlighting recent advancements and emerging trends. By synthesizing the available literature and drawing upon relevant studies,

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we aim to provide valuable insights into the potential of biofortified fruit crops as a sustainable solution for improving nutrition and public health.

APPROACHES FOR BIOFORTIFICATION

Breeding interventions

Breeding interventions play a crucial role in biofortification programmes, where genetic variation affecting mineral traits is identified, stability is assessed under different environmental conditions, and breeding strategies are developed to increase mineral content in edible tissues without compromising yield or quality traits. This approach offers sustainability and has the potential to introduce high-mineral varieties into the market. However, the development of such varieties can be time-consuming because of linkage drag, especially when introgressing traits governing mineral contents from wild relatives. To expedite the process, breeders employ molecular biology techniques like quantitative trait locus (QTL) maps and marker-assisted selection (MAS) to identify and select high-mineral varieties. For map based cloning of genes of interest special mapping strategies can be used for rapidly targeting specific regions of the genome (Yu *et al*. 2021).

Conventional breeding: Conventional breeding in biofortification is limited by the existing genetic variability in the target crop or wild varieties that can cross with the crop. To overcome these limitations, genetic engineering technique like molecular breeding, also known as marker-assisted breeding, has emerged as a powerful tool in modern biotechnology can be used for transferring desirable trait (Dolkar *et al*. 2014). Genomic information is used in marker-assisted breeding to identify and select plants with desired traits, and advancements in genomics have facilitated its rapid expansion. Mutation breeding is another technique extensively employed in biofortification, both in developed and developing countries. It involves inducing mutations in crops using physical or chemical mutagens, leading to increased genetic variability. This approach has proven successful in developing grain varieties with improved quality, higher yields and other desirable traits.

Molecular interventions

For future crop development initiatives, evaluation of genetic resources is also crucial, and analysing such resources for different features gives researchers and scientists a wealth of knowledge they may use to find and choose beneficial genetic resources (Shah *et al*. 2023). Molecular interventions in biofortification encompass various approaches that aim to enhance plant growth and nutrient uptake. Two significant molecular interventions include the use of Plant Growth Promoting *Rhizobacteria* (PGPR) and *Arbuscular Mycorrhizal* (AM) fungi. PGPR are beneficial bacteria that colonize plant roots and promote plant growth through diverse mechanisms. Their use in agriculture is gaining momentum as they provide an attractive alternative to reduce the reliance on chemical fertilizers and pesticides (Compant *et al*. 2019). One such mechanism involves the secretion of phytosiderophores, which facilitate the uptake of micronutrients like iron from the rhizosphere, thereby improving plant nutrition. AM fungi form symbiotic associations with most plants, including major grain crops, vegetables, and fruits, contributing to enhanced nutrient uptake and plant productivity (Schweiger *et al*. 2020). These fungi play a crucial role in improving the mineral nutrition of plants, consequently influencing the nutrient content of plant-derived food products. Innovative breeding methods like intrageneis and cisgenesis have the power to completely change how fruit crop development is done. With intrageneis, a plant's genetic material is altered to improve particular qualities, either by deleting or silencing undesired genes or by introducing helpful genes from the same species. The introduction of foreign genetic material is less of a problem thanks to this method's precision and focused genetic manipulation. The technique may result in the growth of fruit crops with enhanced properties including increased nutritional value, disease resistance, or fruit quality (Holme and Wendt 2019). Contrarily, cisgenesis is comparable to intragenesis but increases the genetic diversity include closely related, sexually compatible species. Comparatively to conventional transgenic methods, this method enables the insertion of genes from the same gene pool, alleviating regulatory problems. Cisgenesis offers hope for improving fruit harvests while preserving genetic compatibility with the intended species (Schaart *et al*. 2016). The root systems of fruit crops, which are in charge of nutrient intake and transportation, are the building blocks of biofortification. This essential step is regulated by molecular those who operate channels and nutrient transporters. For instance, the expression of some genes, such as those encoding the transporters nitrate transporter 1 (NRT1) and iron-regulated transporter 1 (IRT1), is carefully regulated to maximize soil nutrient uptake. In fruit crops, leaves act as the primary sites for photosynthesis and nutritional absorption. It may be possible to increase the nutritional value of fruit by better understanding the molecular mechanisms behind photosynthesis and the production of essential metabolites, such as chlorophyll. Because they increase photosynthetic efficiency, genes for enzymes like protochloro phyllide reductase (POR) have attracted interest (Duan *et al*. 2021). Understanding these pathways might lead to methods for enhancing the nutritious content of fruits. In efforts to improve food through biofortification, the molecular mechanisms controlling fruit growth and ripening are crucial. Fruit size and quality are significantly influenced by genes that produce growth hormones such as auxins, cytokinins, and gibberellins (Seyfferth *et al*. 2020). The flow of nutrients from source to sink organs, including fruits, is facilitated by the phloem and xylem transport systems, which are controlled by certain genes and transporters (Reid *et al*. 2011).

Cultural intervention

Cultural interventions play a significant role in enhancing mineral accumulation in fruit crops for nutritional purposes. Farmers have historically utilized mineral fertilizers to improve plant health, but there are limitations and considerations associated with this approach. One drawback of cultural intervention is the cost and potential negative impact of fertilizers. It is possible that greater fertilizer use will raise the price of producing fruit. But it's vital to remember that fertilizers are quite important for increasing crop yield. Fertilizers improve growth, output, and fruit quality by feeding plants with vital nutrients and its application may boost productivity and offset higher production costs, making it economically viable for farmers. In addition to ensuring a steady food supply, this enhanced yield also permits surplus production, which might cut fruit prices on the market. Thus, while fertilizer costs could increase, the overall result is frequently a greater supply of fruit, which can eventually be advantageous for both farmers and customers, especially those in poverty. The price of fertilizers can in fact deter their frequent usage in poor nations where farmers may lack clear incentives for fruit crop quality and yield enhancement. Using advanced growing media can also boost nutrient absorption, enhancing fruit quality by providing optimal conditions for plant growth and development (Sharma *et al*. 2022). Another effective method under cultural intervention involves using plant growth regulators sprayed onto plants. These substances greatly influence the inner mechanism of plants, affecting their physiological and biochemical processes (Maanik and Sharma 2022).

While essential plant nutrients are typically applied to soil and foliage to maximize economic yields, there is a need to consider the environmental impact of excessive fertilizer application (Dhotra *et al*. 2021). Through irrigation systems, fertilization includes the simultaneous delivery of water and nutrients. This technique is exceptionally effective since it allows for perfect control over the distribution of nutrients to specific plants. Drip irrigation systems are frequently utilized for fertigation in fruit plantations. For instance, a nutrient-rich solution can be directly applied to the root zones of plants in citrus orchards. This method results in healthier trees and better-quality fruit by increasing fertilizer absorption and reducing nutrient waste (Kour *et al*. 2011).

Spot applications entail the deliberate, frequently manual distribution of fertilizers close to the root zones of certain plants. This approach is especially helpful for fruit crops with a dispersed planting pattern, such as blueberries and strawberries. Nutrient intake is maximized and crop competition for nutrients is reduced by putting fertilizers close to the plants.

Biofortification in fruit crops

Apple (*Malus × domestica*): Apple varieties with increased levels of antioxidants such as phenolic compounds, flavonoids, and anthocyanin's have been identified (Strand *et al*. 2018). These compounds have been associated with various health benefits, including their antioxidant and anti-inflammatory properties. Research has shown that nutrient management practices, such as balanced fertilization with macronutrients and micronutrients, can influence the nutrient content of apple fruits (Tagliavini *et al*. 2019). By optimizing nutrient availability and uptake, biofortification efforts aim to improve the nutritional quality of apple crops. Researchers have investigated the introduction of specific genes into apple trees to enhance the production of desired compounds, such as antioxidants or other beneficial phytochemicals (Diaz-Riquelme *et al*. 2017). Genetic engineering offers the potential to directly manipulate the biosynthetic pathways in apple trees, leading to increased levels of target nutrients or bioactive compounds. While biofortification in apple crops shows promise, further research is needed to evaluate the efficacy and safety of biofortified apple varieties. Additionally, consumer acceptance and market considerations play a significant role in the successful adoption of biofortified apple varieties.

Apple biofortification involves the introduction of a stilbene synthase gene from the grapevine (*Vitis vinifera* L.) into apple plants, resulting in the synthesis of resveratrol, a potent antioxidant compound (Tian *et al*. 2017). By genetically modifying apple plants to produce resveratrol, biofortification efforts seek to expand the antioxidant capacity of apples, offering potential health benefits to consumers. The introduction of the stilbene synthase gene into apple plants enables the biosynthesis of resveratrol, which is naturally found in grapes and known for its antioxidant and anti-inflammatory properties (Pilati *et al*. 2007). Through genetic engineering, apple varieties with increased levels of resveratrol can be developed, providing consumers with an apple fruit that offers enhanced antioxidant benefits. Tian *et al*. (2017) reported the successful transformation of apple cultivars using an Agrobacterium-mediated gene transfer technique. A gene termed the Leaf Colour (Lc) gene from maize (maize) was used to genetically modify apple plants, especially the 'Holsteiner Cox' type. These modifications caused these apples to produce substantially larger levels of anthocyanins and flavan-3-ols, which comprise catechins and proanthocyanidins among other natural components (Flachowsky *et al*. 2010). Apples contain enzymes called polyphenol oxidases (PPOs) that cause the fruit to oxidize when it comes into contact with oxygen. When you cut or harm the apple, it begins to brown. Apples can be stored without air, given specific treatments like irradiation, or treated with chemicals and organic compounds that inhibit PPOs to prevent browning. Scientists suppressed the PPOs in the Arctic® apple, a sort of apple that doesn't brown readily. You may purchase 3 different varieties of Arctic® apples: Arctic® Fuji, Arctic® Granny Smith, and Arctic® Golden Delicious. Arctic® Golden Delicious and Arctic® Granny Smith went on sale in 2016, and Arctic® Fuji will follow in 2021 (Lobato-Gomez *et al*. 2021).

Pear (*Pyrus communis*): Biofortification efforts in the pear crop have aimed to enhance its nutritional composition and contribute to addressing nutrient deficiencies. While biofortification research in pears is relatively limited compared to other crops, there have been studies exploring strategies to improve the nutritional value of pears. One approach for biofortification in pears involves conventional breeding techniques. Breeding programs focus on selecting and crossing pear cultivars with improved nutritional profiles, such as increased levels of vitamins, minerals, or antioxidants. Genetic modification allows for the targeted introduction of genes that can enhance the levels of specific nutrients or beneficial compounds. For instance, researchers have investigated the over-expression of genes involved in the biosynthesis of antioxidants, such as anthocyanins, in pear fruits (Han *et al*. 2016). This approach aims to increase the antioxidant capacity of pears and potentially improve their health-promoting properties.

Strawberry (*Fragaria* × *ananassa*): The breeding efforts have been focused on improving the overall nutritional quality and health-promoting properties of strawberries (Singh *et al*. 2022). Genetic engineering techniques have also been utilized to biofortify strawberries. For example, genetic engineering has been employed to increase the levels of vitamin C in strawberries, as well as to improve their resistance to diseases and environmental stresses (Borowski *et al*. 2016). In strawberry, ADP-glucose pyrophosphorylase was suppressed by expressing antisense RNA under the control of a fruit-specific promoter. This prevented the conversion of sugar to starch and resulted in transgenic fruits having up to 47% less starch and up to 37% more soluble sugar (Park *et al*. 2006). Cultural intervention with spray of 900 ppm cycocel yielded top-quality strawberries with high TSS, sugar, vitamin-C, juice content, and low acidity (Kumar *et al*. 2012).

Mango (*Mangifera indica*): Biofortification in the mango crop aims to enhance its nutritional value by increasing the levels of key micronutrients and phytochemicals. While there have been limited studies specifically focused on biofortification of mango, research efforts have explored conventional breeding techniques and biotechnological approaches to improve its nutrient content. One study conducted by Padmesh *et al*. (2013) investigated the potential of conventional breeding to enhance the nutrient content of mango cultivars. The researchers evaluated the variation in mineral composition, including iron, zinc and calcium, among different mango genotypes, and demonstrated significant variability in nutrient content, suggesting the potential for selecting and breeding mango varieties with higher mineral concentrations. In addition to conventional breeding, biotechnological approaches such as genetic engineering have been explored to enhance the nutritional composition of mango. A study by Saranya *et al*. (2017) focused on the genetic transformation of mango to increase the levels of pro-vitamin A carotenoid, such as beta-carotene, which is a precursor of vitamin A. The researchers introduced a carotenoid biosynthesis gene from a different plant species into mango embryogenic callus cells, leading to the development of transgenic mango plants with increased beta-carotene content. Dhotra *et al*. (2021) conducted an experiment on the effects of foliar application of micronutrients on the growth, yield, and quality of Dashehari mango fruits. Different combinations of $Ca(NO_3)_2$, H_3BO_3, and $ZnSO_4$ were applied before the flowering stage and micronutrient treatments improved fruit quality compared to the control.

Citrus (*Citrus* spp.): Conventional breeding methods have been utilized to improve the nutritional content of citrus fruits. Through the selection and crossbreeding of citrus varieties with naturally higher nutrient levels, breeders aim to develop new varieties with improved nutritional profiles. For example, breeding programs have targeted the enhancement of vitamin C content in citrus fruits (Salonia *et al.* 2020). In addition to conventional breeding, genetic engineering techniques have been employed to biofortify citrus crops (Table 1). By introducing specific genes into citrus plants, researchers can enhance the levels of targeted nutrients. For instance, genetic engineering has been used to increase the iron content in citrus fruits by over-expressing iron transporters (Zhang *et al*. 2019). This approach shows promise in addressing iron deficiency, a prevalent micronutrient deficiency worldwide. Citrus biofortification efforts have also focused on enhancing the levels of other essential micronutrients such as pro-vitamin A carotenoid (e.g., beta-carotene) and folate. Genetic engineering approaches have been utilized to increase the accumulation of pro-vitamin A carotenoid in citrus fruits (Pons *et al*. 2018). According to Bakshi *et al*. (2017), the highest fruit nitrogen content (0.06%) was achieved under 100% nitrogen as urea in combination with *Azotobacter* in Kinnow through INM practices. Application of potassium sulphate (10%) and calcium chloride improved the quality of fruit in Eureka lemon (Devi *et al*. 2018). These efforts aim to provide citrus fruits with enhanced nutritional value, particularly in regions where vitamin A deficiency is prevalent.

Banana (*Musa* spp.): Conventional breeding programs have been instrumental in developing biofortified banana varieties. Through traditional breeding techniques, breeders aim to select and crossbreed banana cultivars with improved nutritional profiles. For instance, efforts have been focused on enhancing the levels of provitamin A carotenoids, such as beta-carotene, in banana fruits (Davey *et al*. 2009). These breeding programs aim to develop banana varieties

Table 1 Biofortified cultivars of citrus fruits

Citrus cultivar	Biofortification traits	Reference
Ruby blood red citrus	Deep red colour due to anthocyanins	Butelli *et al*. (2012).
Malta (Maltase) citrus	Sweet taste and high vitamin C content	Medina-Remon *et al*. (2011)
Star ruby grapefruit	Pink-red flesh rich in lycopene	Strother and Lila (2016)
Rio red grapefruit	Red-fleshed with high lycopene content	Dorado *et al*. (2021)

that can contribute to addressing vitamin A deficiency, particularly in regions where bananas are a staple food. Genetic engineering techniques have also been employed to biofortify banana crops. By introducing specific genes into banana plants, researchers can enhance the levels of targeted nutrients. One notable example is the development of biofortified Golden Banana that accumulate provitaminA carotenoids, addressing vitamin A deficiency (Arango *et al*. 2010). Genetic engineering can also be utilized to enhance the levels of other essential nutrients, such as iron and zinc, in banana fruits (Naqvi *et al*. 2009). Researcher have also targeted the reduction of harmful compounds. For instance, efforts have been made to develop biofortified bananas with reduced levels of acrylamide, a potential carcinogen formed during cooking (Joshi *et al*. 2017). These initiatives aim to improve the safety and nutritional quality of banana-based foods . It is true that red bananas, particularly kinds like "Red Dacca" and "Red Cavendish," are a great source of many healthy substances. They strengthen the immune system more than regular yellow bananas since they have more vitamin C content. Additionally, red bananas include potassium, dietary fibre, and antioxidants such phenolic compounds. These antioxidants, which include anthocyanins, have been linked to possible health advantages such antioxidant and anti-inflammatory capabilities (Lobo *et al*. 2010). The production of non-translated pathogen genes to trigger a PR response or to repress viral elements necessary for replication, packaging, or systemic transmission is a key tactic in the battle against viral infections. Six months after the completion of the transgenic plants, all signs of the bunchy top virus illness were eliminated thanks to RNAi-mediated silencing of viral components in banana (Shekhawat *et al*. 2012).

Guava (*Psidium guajava*): Biofortification efforts in guava have been aimed to enhance the nutritional content of this fruit by increasing the levels of essential micronutrients and bioactive compounds. Traditional breeding approaches have been utilized to develop guava varieties with enhanced nutrient profiles. They have focused on increasing the levels of essential micronutrients, such as vitamin C, beta-carotene, and minerals like iron and zinc, through selective breeding methods (Navarro-Tarazaga *et al*. 2016). These breeding programs aimed to address micronutrient deficiencies and improve the overall nutritional value of guava fruits. Genetic engineering techniques have also been employed to biofortify guava crops. Through the introduction of specific genes into guava plants, researchers aim to enhance the production of desired bioactive compounds. The Paluma guava cultivar is widely grown in Brazil and is distinguished by its crimson pulp, high soluble solids content, wonderful flavour, and outstanding agronomic yield. These biofortified guava varieties offer improved nutritional benefits and enhanced antioxidant capacity. In addition to genetic approaches, cultural interventions have been employed to enhance nutrient content in guava. Optimizing agricultural practices, such as appropriate fertilization and irrigation techniques, can improve the nutrient uptake and accumulation in guava plants (Sathya *et al*. 2019). These cultural interventions contribute to the biofortification of guava by ensuring optimal nutrient availability for plant growth and fruit development.

Papaya (*Carica papaya*): One approach in papaya biofortification is genetic engineering to enhance the levels of provitamin A carotenoids, such as beta-carotene. This has been achieved through the introduction of specific genes involved in carotenoid biosynthesis (Shankar *et al*. 2010). The development of biofortified papaya varieties with enhanced vitamin A content can contribute to addressing vitamin A deficiency in populations relying on papaya as a dietary staple (Shankar *et al*. 2010). Another aspect of papaya biofortification is increasing the levels of essential minerals, such as iron and zinc. Genetic engineering techniques have been employed to enhance the mineral content in papaya fruits, aiming to improve their nutritional value (Maxwell *et al*. 2013). In 1998, Hawaii saw the introduction of the first commercially available transgenic papaya containing the PRSV CP gene, the coat protein for the papaya ring spot virus. Variable degrees of resistance to ring spot virus strains from various geographic locations were seen in CP-transgenic papaya plants. The virus can overcome resistance and may lead to pathogenicity since isolates from Florida, the Bahamas, and Mexico delayed and made symptoms milder whereas isolates from Thailand and Brazil delayed symptoms. A homozygous line named Rainbow also showed signs of susceptibility to Taiwanese virus isolates. As a result, the degree of resistance to isolates from various places seemed to vary. Targeting the conserved region of the PRSV CP gene using RNA interference has also been used to try to build broad-spectrum resistance.

Grapes (*Vitis vinifera*): Conventional breeding techniques have been utilized to develop biofortified grape varieties. Through selective breeding, breeders aim to improve the content of desired compounds, such as polyphenols and anthocyanins in grape berries. These compounds contribute to the antioxidant capacity and health-promoting properties of grapes (Di Lorenzo *et al*. 2019). Traditional breeding strategies have historically focused on choosing grape varieties with higher concentrations of certain phenolic chemicals, which improve nutritional characteristics. In addition to conventional techniques, genetic engineering strategies have been used to promote grape biofortification, providing potential new ways to enhance grapevine traits. (Lijavetzky *et al*. 2008). By introducing specific genes or modifying gene expression, researchers can enhance the accumulation of target compounds in grape berries. For example, transgenic grapevines with increased levels of resveratrol, a polyphenol with potential health benefits, have been developed (Vezzulli *et al*. 2007). Genetic engineering allows for precise manipulation of metabolic pathways involved in the biosynthesis of desired compounds, leading to enhanced nutritional properties in grapes. Moreover, agronomic practices can influence the nutritional composition of grapes. For instance, the application of different fertilization regimes, irrigation strategies, and canopy management techniques can impact the accumulation of phenolic compounds in grape berries (Cortell and Kennedy 2006).

Pomegranate (*Punica granatum*): Pomegranate Solapur Lal is a hybrid variety and contains high iron (5.6–6.1 mg/100 g), zinc (0.64–0.69 mg/100 g) and vitamin C (19.4–19.8 mg/100 g) in fresh arils. It has been released and notified in 2017 for semi-arid regions of the country. Its average fruit yield is 23.0–27.0 t/ha. This biofortified variety has been developed by ICAR-National Research Centre on Pomegranate, Pune, Maharashtra (Anonymous 2017)

Aonla (*Phyllanthus emblica*): Aonla is already known for its high levels of vitamin C and other beneficial compounds. Traditional breeding efforts could be focused on further enhancing the nutritional profile of aonla through selection and cross-breeding techniques (Singh *et al*. 2019). Additionally, genetic engineering approaches could be explored to introduce genes responsible for increased nutrient content in aonla, but it is important to consider the potential regulatory and public acceptance challenges associated with genetically modified crops (Chaurasia *et al*. 2009). Mulching material (Black Polythene) effect the quality parameters of aonla cv. NA-7 resulting improved quality fruits (Iqbal *et al*. 2015).

Conclusion

Malnutrition and covert hunger are widespread problems that impact both wealthy and developing nations and have terrible global repercussions. The recent effects of the pandemic highlight how urgent it is to change our food systems in order to solve shortages in our food supply. Additionally, the need to improve the nutritional value of plant-based foods (PBFs) is highlighted by climate change estimates that indicate increased inequality and poverty in emerging nations. Offering a potential remedy for micronutrient deficiencies and covert hunger, it entails improving PBFs with nutritional density and bioavailability by methods including plant breeding, transgenic, and mineral fertilizer applications. To successfully promote, cultivate, and consume biofortification, socio-political and economic issues must be resolved. It is crucial to have an integrated strategy that involves legislators, farmers, food developers, genetic engineers, dietitians, and educators in order to successfully address hidden hunger through biofortification. Biofortification strategies should be tailored to local nutritional issues while taking cultural variations in consumer acceptability into account. In conclusion, biofortification offers a potential range of methods for improving nutritional health worldwide, bringing us one step closer to reducing hunger and malnutrition.

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