International Journal of Economic Plants 2022, 9(3):184-193

Review Article

Doi: HTTPS://DOI.ORG/10.23910/2/2022.460a

Biofortification of Vegetable Crops: An Option for Mitigating Hidden Hunger

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Article History

Article ID: IJEP460a
Received on 01st February, 2022
Received in revised form on 26th June, 2022
Accepted in final form on 17th July, 2022

Abstract

Micronutrient malnutrition is known to affect more than half of the world's population and considered to be among the most serious global challenges to humankind. One such approach to combat the issue of micro nutrient malnutrition is through biofortification, a process of breeding nutrients into food crops which provides a comparatively cost-effective, sustainable and long-term means of delivering more micronutrients to rural populations in developing countries. Biofortification of vegetables with vitamins and micronutrients is the present day need for developing countries to overcome various health issues. Currently, agronomic conventional plant breeding and genetic modification are three common approaches for biofortification of vegetable crops. Agronomic biofortification is the application of fertilizers to increase the micronutrients in edible parts. Iron level of Amaranthus plants can be increased by using *Spirulina platensis* as microbial inoculant when compared with control. In conventional plant breeding, parent lines with high vitamin or mineral levels can be crossed over several generations to produce plants that have the desired nutrients. IARI, New Delhi developed first ever indigenously bred biofortified beta carotene (8–10 µg g^{-1}) rich cauliflower variety i.e. Pusa Betakesari-1 through marker assisted backcrossing. Transgenic approaches are advantageous when the nutrient does not naturally exist in a crop. Increased nutritive value in potato may be achieved by expressing a non-allergenic seed albumin gene from *Amaranthus hypochondriacus* by protein-rich potato expressing the seed protein gene AmA1 (Amaranth Albumin 1). Many genes are available for the target traits by which it will be possible to enhance micronutrient in vegetables. These approaches can be very much helpful in improving the level of micronutrients and vitamins by several-fold in different vegetables.

Keywords: Challenges, biofortification, methods, malnutrition, vegetables, perspectives

1. Introduction

Micronutrient deficiencies lead to a global problem of malnourishment of the population due to inadequate availability of vitamins and other micronutrients which affects human health. A different type of dietary insufficiency affects half of the world's population, with developing countries bearing the brunt of the issue (Ortiz-Monasterio et al., 2007). The biggest challenges are hunger and malnutrition due to the ever-increasing world population. Malnutrition is a condition that results from eating diet which does not supply a healthy amount of one or more nutrients. It leads to developmental delay, disabilities, low immunity, various illness and poor cognitive abilities. According to WHO, Malnutrition includes both under nutrition as well as over-nutrition and refers to deficiencies, excesses or imbalances in the intake of energy, protein and other nutrients. To maintain a balanced lifestyle, humans need a small number of macro-elements, a trace number of microelements (Fe, Cu, Zn, I, and Se), and vitamins, as well as a significant amount of starch, protein, and lipids (Welch, 2002). Provitamin A, Fe, I, Zn, and Se deficiency are all stated to have a high percentage of disease burden and a negative effect on the population (Black et al., 2008, Stein, 2010). Vitamin A deficiency is dominant in developing countries among children and women which leads to >600, 000 deaths each year globally among children <5 year of age. The micronutrient malnutrition of the population is dominated by 60% iron, 30% zinc, 30% iodine and 15% selenium (Gomathi et al., 2017). Sustainable solutions to malnutrition will only be found by closely linking agriculture to nutrition and health and by formulating agriculture, nutrition, and health policies to reflect this need (Graham et al., 2007, Hawkes and Ruel, 2006). In human nutrition micronutrients play an important role, in prevention and treatment of various illnesses and also promote mental and physical wellbeing (Tripathy et al., 2020).Vegetables are a rich source of nutrients and as per the recommendation made by ICMR, an average man with vegetarian or non-vegetarian food habits should consume 300 g day^{-1} $capita^{-1}$ comprising of 125 g leafy vegetables, 100 g tubers and 75 g of other vegetables. According to an estimate, almost 800 million people all over the world are malnourished, around 98% of whom are residing in developing countries (Sinha et al., 2019). In addition to this, around 2 billion people globally experience another type of hunger, known as hidden hunger, which is caused by poor intake of essential micronutrients in the everyday diet (Muthayya et al., 2013; Gillespie et al., 2016)

Hidden hunger is a lack of vitamins and minerals. Hidden hunger occurs when the quality of food consumed does not fulfil people's nutrition needs, resulting in a lack of micronutrients such as vitamins and minerals required for growth and development (Rehan et al., 2020). Nutritional supplements are one solution, but these are expensive. By enrichment of staple food with required micronutrients is one way to fight this hidden hunger. Several agricultural strategies like fertilization with micronutrients, breeding for higher micronutrient status of crop variety, making transgenic and biofortification can all help to alleviate hidden hunger. According to estimates, around 30–40% of preschool children and pregnant women in developed countries suffer from iron deficiencies(Lucca et al., 2006). Besides hunger, malnutrition resulting from the intake of food poor in nutritional quality, particularly lacking in micronutrients, has been recognized as a serious global health problem, more so among children, women of reproductive age, pregnant and lactating women in the developing world. Efforts are underway to address this hidden hunger by various means. Biofortification is a sustainable option to combat micronutrient malnutrition and complements dietary diversification, food fortification and supplementation that are currently employed to address micronutrient deficiency in human diets (Ramesh et al., 2018). From an economic viewpoint, biofortification is a one-time investment and offers a cost-effective, long-term, and sustainable approach in fighting hidden hunger because once the biofortified crops are developed; there are no costs of buying the fortificants and adding them to the food supply during processing (Hirschi, 2009; Hefferon, 2016; Meenakshi et al., 2010).

According to World Health Organization (estimation, biofortification could help cure two billion people suffering from iron deficiency-induced anemia (McLean et al., 2009). For humans, agricultural products are the primary source of nutrients, especially for those living in developing countries (Graham et al., 2001). Though conventional cultivation practices may partly improve the nutritional content in plant foods but an advanced research to combat nutritional deficiencies lead to the development of biofortification.

2. Biofortification

The word "Biofortification" is derived from a Greek word "Bios" means "life" and a Latin word "fortificare" means"make strong". In a single word Biofortification means make life strong. It is a process of increasing the bioavailable concentrations of an element in edible portions of crop plants through agronomic practices, conventionl breeding or through genetic modification. It provides a more cost-effective, long-term, and sustainable method of supplying additional micronutrients in food. This approach will decrease the number of severely malnourished people as well as help them maintain improved nutritional status. Moreover, biofortification provides a feasible means of reaching malnourished rural populations who may have limited access to commercially marketed fortified foods and supplements. This strategy helps to put the micronutrient-dense trait in those varieties that already are popular and are market oriented. Developing biofortified crops also improves their efficiency of growth in soils with depleted or unavailable mineral composition (Borg et al., 2009). Although biofortified staple foods cannot provide as high a level of minerals and vitamins per day as supplements or industrially fortified foods, but they can aid by increasing the daily adequacy of micronutrient intakes among individuals throughout the life cycle (Bouis et al., 2011). The breeding of plants for enhancement of bioavailability of micronutrients in the targeted edible food is the low-cost approach for poor countries and their people who cannot afford high-quality food. Thus mitigation of micronutrient malnutrition can be done by this approach, and this will ensure better health (Waters and Sankaran, 2011).

Table 1: Deficiency of Micronutrients

Vitamin / Mineral	Deficiency disease/ disorder	Symptoms
Vitamin A	Loss of vision	Poor vision, loss of vision in darkness (night), sometimes complete loss of vision
Vitamin B1	Beriberi	Weak muscles and very little energy to work
Vitamin C	Scurvy	Bleeding gums, wounds take longer time to heal
Vitamin D	Rickets	Bones become soft and bent
Calcium	Bone and teeth decay	Weak bone, tooth decay
Iodine	Goiter	Glands in the neck appear swollen, mental disability in children
Iron	Anemia	Weakness

3. Criteria of Biofortification

Major criteria of biofortification are as follows:

- Micronutrient enrichment must be effective
- Stability
- High yield
- Efficacious bioavailbility
- Taste and cooking quality
- Consumer acceptance
- Disease resistance

4. Importance

- To improves the plant or crop quality.
- To increase the nutritional quality in daily diets.
- To overcome malnutrition in human beings.
- To promote food security.
- Application of biofortified crops would benefit farmers by increasing their income in the long term.
- It is especially important for poor rural community with finite access to a varied diet, fortified foods or supplements.

5. Objectives

- To produce vegetable crops containing highly available micronutrients like iron, zinc and vitamin A for preventing global deficiency of these nutrients.
- To screen for biofortification of vegetable crops from existing germplasm.
- To study the efficacy of mineral nutrients.

6. Advantages

- Increment of nutritional quality in daily diets
- Increase in yield and crop quality.
- Reduced adult & child mortality.
- Biofortified crop system is highly sustainable.
- Healthier populations with strong and quick immune responses to infections.
- Biofortified crops are also a feasible means of reaching rural populations who may have limited access to diverse diets or other micronutrient interventions.

7. Success of Biofortification Depends on

- First, a successful breeding programme should include high nutrient density along with high yields and high profitability.
- Second, the effect of fortified foods must be demonstrated- there should be an improvement in micronutrient status of human subjects must be shown to improve when consuming the biofortified varieties as normally eaten. Thus, these nutrients must be bioavailable and must be retained in cooking and processing.
- Third, the farmers must cultivate these biofortifed crops and should reach those suffering from micronutrient malnutrition in significant numbers

8. Methods of Biofortification

Biofortification can be achieved through three strategies:

1. Agronomic biofortification
2. Conventional plant breeding
3. Genetic engineering

8.1. Agronomic biofortification

Application of micronutrient rich fertilizers to increase the micronutrients in edible parts (Prasad et al., 2015). Most suitable micronutrients for agronomic biofortification are Zinc (foliar application of $ZnSO_4$), Iodine (Soil application of iodide or iodate), Selenium (as selenate). Foliar application is the quick and easy method of nutrient application to fortification of micro nutrients (Fe, Zn, Cu etc.) in plants. According to White and Broadley (2005), the degree of agronomic biofortification success is proportional to the mobility of mineral elements in the soil and in the plant.

Table 2: Source of nutrients from vegetables (Food and Nutrition Board, 2013)

Nutrients	Vegetables
Carbohydrate	Sweet potato, potato, cassava
Protein	Pea, lima bean, french bean, cowpea
Vitamin A	Carrot, spinach, pumpkin
Vitamin B1	Tomato, chilli, garlic, leek, pea
Vitamin C	Chilli, sweet pepper, cabbage, drumstick
Calcium	Hyacinth bean, amaranthus, palak
Iron	Amaranthus, palak, spinach, lettuce, bitter gourd
Phosphorous	Pea, lima bean, taro, drumstick leaves
Vitamin B5	Palak, amaranthus, bitter gourd, pointed gourd
Iodine	Tomato, sweet pepper, carrot, garlic, okra
Sodium	Celery, green onion, Chinese cabbage, radish

8.2. Biofortification of vegetable crops with iodine

Tomato plants can tolerate high levels of iodine, stored both in the vegetative tissues and fruits at concentrations that are more than sufficient for the human diet and conclude that tomato is an excellent crop for iodine biofortification program. The fruit concentration of iodine detected in 5mM iodide–treated plants was more than enough to cover a daily human intake of 150 µg (Landini et al., 2011).

8.3. Biofortification of vegetable crops with iron

Iron level of Amaranthus plants can be increased by using *Spirulina platensis* as microbial inoculant when compared with control and also reported that *Spirulina platensis* has been used as bio-fortifying agent to enhance the iron status in *Amaranthus gangeticus* plant. Seed treatment in various forms was given to the seeds of *Amaranthus gangeticus* viz., seed soaking for different times with *Spirulina platensis* and seedtreatment with different ratios of vermicompost and organic manure. The sample with two hours of soaking recorded a high content (18.35± 0.03 mg g^{-1}) of iron (Kalpana et al., 2014).

8.4. Biofortification of vegetable crops with zinc

Yudicheva (2014) conducted study on effect of environmentally safe new generation organic fertilizer "Riverm" on zinc content in capsicum, eggplant and tomato. Capsicum which were grown with the use of "Riverm" accumulated in their structure 3.94 mg kg^{-1} of zinc, that is 0.26 mg kg^{-1} (or 6.60%) more than in vegetables grown under standard conditions (without fertilizer). The reference sample of eggplant contained 3.42 mg kg^{-1} of zinc and the studied sample contained 3.68 mg kg^{-1} i.e., showing an increase in zinc content to 7.10%. The content of biofortified tomatoes included 3.83 mg kg^{-1} of zinc, and the tomatoes grown without the use of fertilizer contain only 3.51 mg kg^{-1} i.e. increasing the amount of recorded investigational micronutrients to 0.34 mg kg^{-1} (or 8.59%) as shown in Figure 1.

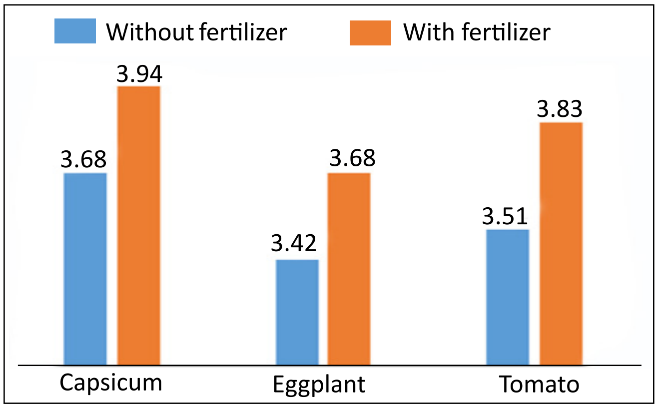

Figure 1: Effect of organic fertilizer "Riverm" on Zn content in solanaceous vegetables (Yudicheva, 2014).

8.5. Biofortification of vegetable crops with selenium

Adhikari (2012) studied selenium content in three varieties of onion i.e.Summit, Hytec and Red Baron through foliar application of a solution of 77Se(IV) that was enriched to 99.7%. He treated these varieties with three treatments as shown in table and found that highest selenium content is found in Red Baron variety when the treatment 50 mg selenium is applied. The Se concentration increased with increasing Se fertilization for all varieties.

Table 3: Biofortification of Se in onion (Adhikari, 2012)

Varieties	Treatments		
	Control	20 mg Se	50 mg Se
Summit	0.07	2.95	6.11
Hytec	0.04	2.66	7.46
Red Baron	0.05	2.65	8.31

8.6. Conventional plant breeding

Precedent plant breeding focus on yield attributes and resistance breeding from last four decades and lack of priority on nutritional aspects leads to decreased amount of nutrient status in the existed varities. Recent progress in conventional plant breeding has given emphasis on fortification of vitamins, antioxidants and micronutrients in edible parts. Through correct selection of breeding material, conventional breeding practices help in improving the concentration of β-carotene, carotenoids, amino acids, amylase, carbohydrates, and other minerals to increase nutritional efficiency (Gregorio et al., 2000). This is an ecologically and economically stable process of crop development for nutraceuticals values of the food. Popular conventional breeding methods like selection, introduction, and hybridization have been exploited for developing nutraceutical values in vegetables as well as tuber crops. Severalresistant sources of nutraceuticals have been identified and transferred in popular cultivars through traditional breeding methods.

8.7. Breeding Criteria for biofortification of vegetables

- Crop yield must be maintained.
- The enriched micronutrient should have significant effect on human health.
- The trait should be stable between generation and in various ecological zones.
- The bioavailability of micronutrients in enriched lines must be tested in humans.
- Taste and cooking quality must be checked.
- The variety must be widely accepted by farmer (Welch and Graham, 2004).

Cauliflower: In cauliflower, Pusa Betakesari-1 have been released in 2015–16 by IARI, New Delhi as first ever indigenously bred biofortified variety through marker assisted backcrossing containing high beta carotene 8–10 µg g^{-1} and matures ready for harvesting during December-January, hence belonging to the mid-late maturity group of Indian cauliflower. It is an attempt to tackle beta carotene deficiency related malnutrition problem in India (Parulekar et al., 2019). Its curds are orange colored, compact and very attractive with semi self-blanching growth habit.

Sweet potato: The main aim of biofortification programs is to replace lowpro-vitamin A white-fleshed sweet potato cultivars with high pro-vitamin A orange-fleshed varieties (Gomathi et al., 2017). Furthermore, it has been shown that retention of beta carotene from orange fleshed sweet potatoes when

Steps in biofortification by conventional plant breeding

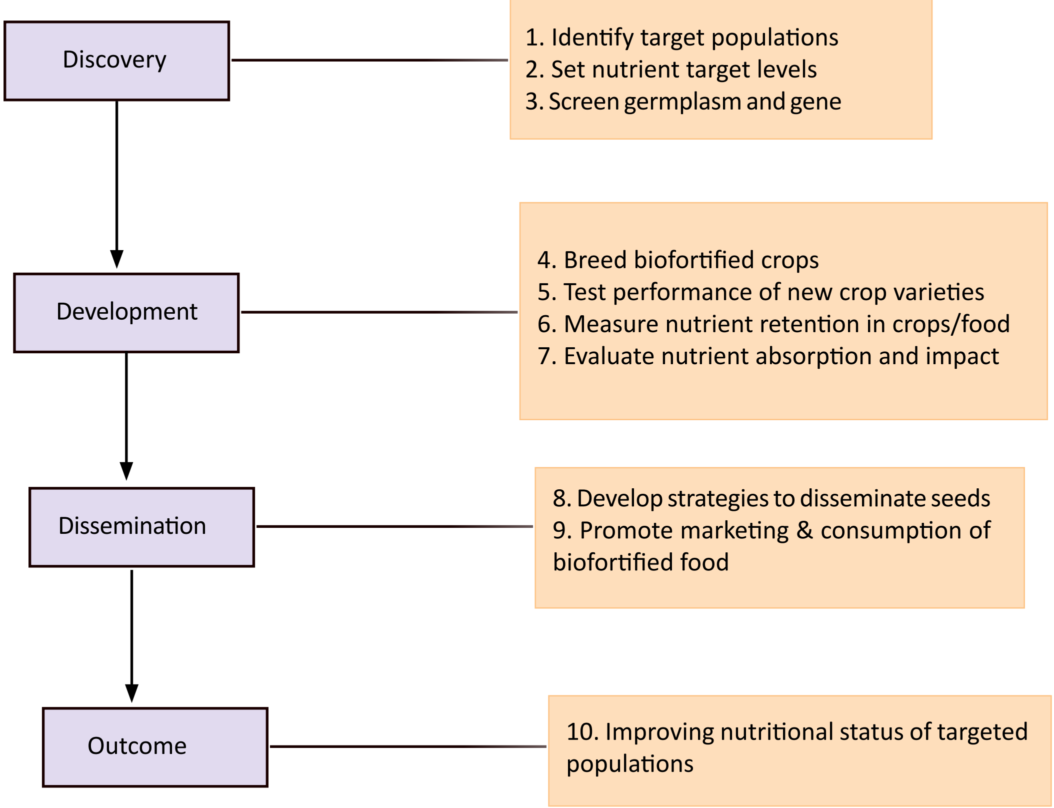

Table 4: Examples of Biofortificationin vegetable crops

Crop	Biofortified element/ mineral/ Vitamin	References
Tomato	Folate, Beta-carotene and lycopene, Zinc, Iodine	Rosati et al., 2000
Potato	Amino acid, protein, anthocyanin, starch	Yang et al., 1989
Onion, Broccoli	Selenium	Adhikari, 2012
Lettuce, Beans	Iron	Goto et al., 2000
Brassica spp.	Selenium, carotene	Seppanenet al., 2010
Sweet potato	Carotene, Protein	Haskell et al., 2004
Spinach	Iodine	Zhu et al., 2003
Pumpkin	Carotenoids	Carvalhoet al., 2014

Table 5: Donor parents having neutraceuticals values in different vegetable crops

Crop	Trait	Donor(s)
Tomato	High ascorbic acid Pro-vitamin A (beta carotene)	*Solanum pimpinellifolium*, Double Rich Crimson and Caro Red
Potato	High protein content	*Solanum phreak*, S. vermeil
Pea	Protein	GC 195, Kinnaird, Loxton
Pumpkin	Carotene	Golden Delicious
Carrot	Vitamin- A	PusaMeghali
Pepper	Carotene	Douxed Alger

Table 6: Sweet potato

Variety	Character	Developing Institute	Source
Bhu Sona	• Developed through pureline selection • High β-carotene (14.0 mg/ 100 g) as compared to 2.0– 3.0 mg/100g in popular varieties • 27 – 29% dry matter • Total sugars 2–2.4% • Released in year 2017	CTCRI, Thiruvananthapuram	Yadav et al., 2017
Bhu Krishna	• Developed through pureline selection • High anthocyanin (90.0 mg/100g) • Tolerant to high salinity • Dry matter: 24.0–25.5% • Starch: 19.5% • Total sugar: 1.9–2.2% • Released in year 2017	CTCRI, Thiruvananthapuram	Yadav et al., 2017
Sree Kanaka	Tubers with dark orange flesh colour and has very high beta carotene content.	CTCRI, Thiruvananthapuram	(Anonymous, 2013)

boiled is very high with about 80% of the initial concentration (Van Jaarsveld et al., 2006). Some of the released biofortified sweet potato varieties are discussed in table.

Potato: *Kufri Neelkanth*

It produces attractive purple coloured ovoid uniform tubers with shallow eyes, yellow flesh, good storability, medium dry matter (18%) with excellent flavour. It possses higher anti-oxidants as compared to other red-skin indigenous varieties. It is main season table potato variety having medium maturity with high tuber yield, field resistance to late blight, good keeping/ culinary quality and suitable for growing in North-Indian plains. It is a clonal selection from the cross between MS/89–1095 × CP3290 developed at CPRI, Shimla (Luthra et al., 2020).

Cassava: *Sree Visakham*

It is a hybrid between a local cultivar and a Madagascar variety developed at CTCRI, Thiruvananthapuram. It is rich in carotene content i.e. 466IU/100g. Starch content in fresh tubers 25–27%. Maturity period is 10 months and avarage yield 35–38 t/ha (Anonymous, 2013) www.ctcri.org).

Carrot: MadhubanGajar: Shri Vallabbhai Vasrambhai Marvaniya, is a progresssive farmer from Gujarat has developed Madhuban Gajar through selection. Higher β-carotene content (277.75 mg kg^{-1}, source of Vitamin A) and iron content (276.7 mgkg^{-1}). He has been conferred with a National Award by the President of India during Festival of Innovation (FOIN) in 2017 and also conferred with Padma Shri in 2019 for his extraordinary work in this field (Anonymous) www.nif.org.in).

Pusa Meghali: Highest beta carotene content–11,571 IU/100g developed through selection by crossing Pusa Kesar and Nantes. Developed at IARI, New Delhi.Average yield of roots is 25–30 t ha^{-1}. Variety having orange coloured flesh in the tropical group. It is suitable for early sowing and matures in 100–120 days.

Table 7: Biofortification in Cowpea

Variety Name	Release Year	Iron Content	Zinc Content	Av. Yield (kg ha^{-1})
Pant Lobia-1	2008	82 ppm Fe	40 ppm Zn	1500
Pant Lobia-2	2010	100 ppm Fe	37 ppm Zn	1500
Pant Lobia-3	2013	67 ppm Fe	38 ppm Zn	1500
Pant Lobia-4	2014	51 ppm Fe	36 ppm Zn	1700

(Anonymous, 2015)

Radish

PusaGulabi: It is first pink fleshed radish variety released in 2013 IARI, New Delhi. It is high in total carotenoids, anthocyanin and ascorbic acid content which grows exceptionally well in the heat of summer. Medium root size, cylindrical shape (Anonymous, 2015) (www.iari.res.in).

PusaJamuni: It is first purple fleshed nutritionally rich variety high in anthocyanin and ascorbic acid content.Released in

2012 IARI, New Delhi (Anonymous, 2015) (www.iari.res.in).

Brinjal: Pusa Safed Baingan-1

It is an improved nutritionally rich variety released by IARI in 2018. It has high total phenol content (31.21 mg 100 g^{-1}) and high antioxidant activity (3.48 mg 100 g^{-1}). It is the first white coloured oval fruited brinjal variety suitable for cultivation in kharif season in north plains, which has been developed by single plant selection from an indigenous material collected from the farmer's field of West Garo Hills, Meghalaya by the Division of Vegetable Science, ICAR-IARI, Pusa, New Delhi (Kumar et al., 2021).

Cowpea: A research conducted at GBPUAT, Pantnagar, India and two early-maturing high-iron and zinc fortified varieties, Pant Lobia-1 (82 ppm Fe and 40 ppm Zn) and Pant Lobia-2 (100ppm Fe and 37 ppm Zn), have been developed by conventional plant breeding and released in 2008 and 2010 respectively (Boukaret al., 2011).

Amaranthus: Pusa Kiran

It is a rich in iron content and developed through natural crossing between *Amaranthus tricolor* and *Amaranthus tristis*. Glossy green leaves and stem, average yield is 55 t ha^{-1}.

Limitations in selective breeding approaches

- Low heritability.
- Lack of genetic diversity for micronutrients
- Lack of sufficient variation among genotypes for desired trait.
- Linkage drag.

8.8. Genetic engineering

Genetic engineering techniques utilize an unlimited pool of genes to produce new cultivars through transfer of desirable characters from one organism to another to develop elite cultivars, thereby improving its value. Lack of sufficient variation among the genotypes for the desired trait within the species, or when the crop itself is not suitable for conventional plant breeding (due to lack of sexuality;) then genetic engineering offers a valid alternative for increasing the concentration and bioavailability of micro nutrients in the edible crop tissues (Prasad et al., 2015). Also recent development in genetic engineering techniques allows for the incorporation of traits that are not possible to achieve by traditional breeding (Chaudhary et al., 2019, Rana et al., 2019).Transgenic crops are genetically modified crops in which not only the nutritional quality is enhanced but also provides protection against insect, viruses and pathogens. Genetic modification is done in vegetable crops to improve characters such as better flavour, higher nutritional status, to decrease bitterness, slow ripening, seedless fruit, increased sweetness and to reduce anti-nutritional factors (Tripathy et al., 2020).

8.9. Tomato

Anthocyanin enrichment of tomato fruit by metabolic engineering: To increase the anthocyanin content of the tomato fruits by fruit specific expression of two transcription factors Rosea1 and Delila isolated from *Antirrhinum majus*.The transgenic plants were identical to the control plants, except for the accumulation of the average anthocyanin content of the transgenic fruit was 0.1 mg g^{-1} fresh weight, which were 70–100 folds higher than that of the control fruits thus giving the fruit a purplish colour (Maligeppagol et al., 2013).

Estimation of antioxidants: The antioxidant capacity was significantly higher in the transgenic fruits (0.0506% AEAC) than in the controls and was 6.2 times higher than that of the commercial control fruits and nearly double than that of the wild type control fruits.

Estimation of carotenoids: The total carotenoid content of the transgenic fruits (13.89 mg/100 g) was on par with that of the wild type control, while it was nearly two fold higher than that of commercial control fruits.

Estimation of lycopene: The lycopene content of the transgenic fruits and wild type control fruits did not differ significantly and was 10.93 mg and 12.65 mg 100 g^{-1} fruit respectively, whereas commercial control fruits had only half as much lycopene as the anthocyanin-rich fruits (Maligeppagol et al., 2013).

8.10. Potato

Protein-rich Potato: Increased nutritive value may be achieved in potato by expressing a non-allergenic seed albumin gene from *Amaranthus hypochondriacus* by protein-rich potato expressing the seed protein gene AmA1 (Amaranth Albumin 1). At the biochemical level, expression of AmA1 in both categories of transgenics leads to a high increase in all essential amino acids, particularly lysine, tyrosine, and the sulfur amino acids with corresponding increase in total protein content (Chakraborty et al., 2000).

Starch-rich potato: Starch is the primary storage component of carbohydrate in potato tubers accounting up to 70% of tuber dry matter. Bacterium *Escherichia coli* gene glg C16 encoding bacterial ADPGP Pase when transferred into potato, the transgenic plant showed high starch content in the tubers (Stark et al., 1992).

8.11. Enhancing protein content in Cassava

In order to increase the nutritional quality of cassava storage roots, which contain up to 85% starch of their dry weight, but are deficient in protein, a synthetic ASP1 gene encoding a storage protein rich in essential amino acids (80%) was introduced into embryogenic suspensions of cassava via Agrobacterium-mediated gene transfer. They found that transgenic varieties are rich in proteins as compared to the control which are deficient in protein (Zhang et al., 2003).

8.12. Beta- carotene rich cauliflower

Cauliflower Or gene represents a novel gene mutation. It causes many low pigmented tissues of the plant, most noticeably the edible curd and the shoot meristem to

Table 8: Recent updates of transgenic research in potato for quality improvement

Sr. No.	Quality trait	Gene	Source
1.	Amino acid-rich storage protein	AmA1	*Amaranthus hypochondriacus*
		tar1 (tarin)	*Colocasia esculenta*
		Boxla, BoxIIa, BoxlaIIa 2	*Bertholletia excels* (Brazil nut)
2.	High amylose starch	SBE I antisense	Potato
3.	Carbohydrate	SUSI (sucrose synthase)	Potato
4.	High tuber galactose	stUGE451 and stUGE5I	Potato
5.	High tuber fructose	xylA (glucose isomerase)	*Thermus thermophilus*

(Pandey et al., 2005)

accumulate high levels of β-carotene and turns these tissues orange. The Or gene has been isolated by a map-based cloning strategy. This gene appears to represent a regulatory gene in controlling carotenoid accumulation (Zhou et al., 2008).

8.13. Cabbage

Red cabbage providing big amounts of anthocyanins and presenting high antioxidant properties which may decrease the risk of cardiovascular diseases, brain disorders and cancer (Draghici et al., 2013).

8.14. Lettuce

Salad crop rich in Vitamin A, C, Ca but has low iron content. A soybean ferritin gene has been used to improve Fe content and yield (Goto et al., 2000).

Potential risks or concerns from use of GM Foods

- ➢ Alteration in nutritional quality of foods
- ➢ Potential toxicity and allergenicity from GM foods
- ➢ Possible creation of new toxins
- ➢ Threat to crop genetic diversity
- ➢ Concerns of organic and traditional farmers
- ➢ Limited access to seeds through patenting of GM food plants (Uzogara, 2000).

9. Future Challenges

- ▪ Consumer preference.
- ▪ Awareness generation.
- ▪ Research intervention.
- ▪ Decrease the level of anti-nutritional compounds.
- ▪ Enhancing the mineral uptake efficiency of the important crops.
- ▪ Promoting large-scale prospective studies on assessing the effects of nutrient enhancement in major staple crops to reduce malnutrition-related disorders in the future.
- ▪ Availability of choice of nutrient rich foods and vegetables in the market.
- ▪ Low cost nutrient rich food product will help in reducing the malnutrition status of India.
- ▪ The biofortified crops have demonstrated increased health benefits.

10. Conclusion

Hunger and malnutrition are major issues which need attention on priority. Biofortification provides a feasible means of reaching malnourished populations in relatively rural areas, delivering naturally fortified foods to people with limited access to commercially-marketed fortified foods, which are more readily available in urban areas. Development, production and consumption of biofortified vegetables need to be popularized for preventing various health issues. Thus, the suitable remedy to eliminate undernutrition as a public health problem is to provide higher consumption of a wide range of non-staple foods in developing countries.

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