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Biofortification as an Opportunity to Mitigate Hidden Hunger

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INTRODUCTION

Different types of major health problems exist among the poor in India due to micronutrient deficiencies. Staple crops have been biofortified to address micronutrient deficiencies in developing countries while fewer efforts have been put to biofortify fruit and vegetables with phytonutrients. This may be attributed to the availability of pharmaceutical supplements having plant-derived nutrients and less regulatory restrictions in comparison to introduction of novel food products. The traditional approaches focused on fortification of normally consumed foods, like milk, flour, oils and salt and distribution of iron-folate and vitamin A tablets as supplements. A more recent approach involves breeding new varieties of horticultural crops containing increased amount of micronutrients. Biofortification is an attractive and alternative opportunity to increase the nutritional value of fruits and vegetables without necessarily increasing intake of supplements (Brinch et al., 2007). It may be defined as increasing the concentration of plant-derived nutrients over and above in the edible organ at the time of growth and development. It is an upcoming, cost-effective, promising and sustainable method of providing micronutrients to a population having limited availability of diverse diets and other micronutrients and can be easily implemented to address malnutrition among such people. It involves only a one-time investment in plant breeding thus making it a promising and cost-effective approach. Several traits such as slow ripening, higher nutritional status, better flavor, seedless fruit, less bitterness, increased sweetness and reduced anti-nutritional factors in horticultural crops have been genetically modified (Gomathi et al., 2017). Various biofortification programs have been conceded in potato, cassava, beans, sweet potato, bananas, tomatoes, sweet-corn, broccoli and cow pea through the joint efforts of national and international organizations (Table 1).

Table 1: Biofortification in various vegetable crops

Crop	Biofortified element/mineral/vitamin
Tomato	Chlorogenic acid, stilbene, flavonoids, anthocyanin, Folate, phytoene, lycopene β-carotene, provitamin A, Zinc, Iodine
Potato	Amin acid, protein, anthocyanin, starch, carbohydrate (fructan)
Onion, Broccoli	Selenium
Lettuce, Beans	Iron
Carrot	Calcium
Radish	Selenium
Brassica spp.	Selenium, carotene
Cassava	Protein, carotene and mineral contents Zn, Se, Cu, I
Sweet potato	Protein ,Carotene
Broccoli	Selenium
Cucumber	Potassium
Spinach	Iodine
Pumpkin	Carotenoids

Significance of Biofortification

Vitamin A, iron, zinc, calcium, folic acid, vitamin D iodine and selenium deficiency are predominant among the malnourished population and biofortification can provide naturally-fortified foods to such people who have limited access to commercially-marketed fortified foods. It cannot deliver much high level of minerals and vitamins per day like supplements or industrially fortified foods, but can help in increasing daily sufficiency of micronutrient intakes among individuals (Bouis et al., 2011). Biofortification cannot treat micronutrient deficiencies or eliminate them in all population groups but it can complement other existing interventions to provide micronutrients to the most deprived people in a comparatively inexpensive and cost-effective way. For instance, according to World Health Organization (WHO) estimation, biofortification could help cure two billion people suffering from iron deficiency-induced anemia.

Biofortification Approaches

Depending on the crop and the nutrient that is targeted, biofortified crops can be achieved through three strategies:

- Agronomic biofortification
- Conventional plant breeding
- Genetic engineering

Agronomic Biofortification

Application of fertilizers to increase the micronutrients in edible parts (Petry et al., 2014). Most suitable micronutrients for agronomic biofortification are Zinc (foliar applications of $ZnSO4$), Iodine (Soil application of iodide or iodate), Selenium (as selenate). Foliar application is a fast and easy method of nutrient application in plants for fortification of micro nutrients like Fe, Zn, Cu etc. It has also been observed that the mycorrhizal associations increase Fe, Se, Zn and Cu concentrations in crops. AM-fungi increase the uptake and efficiency of micronutrients like Zn, Cu, and Fe etc. Sulphur oxidising bacteria increases the sulphur content in onion.

Biofortification through Conventional Breeding

It is the most convenient method to improve plants and now a days modern plant breeding is also targeting towards achieving nutritional quality in addition to get higher yields. Thus, biofortification can target for nutrient fortification in crop plants by collective efforts of modern breeding, transgenic and biotechnological approaches, improved agronomic practices and microbiological interventions. All such kind of efforts will lead to a sustainable and long-term strategy to deal with negative impacts of vitamin and nutrient deficiencies resulting into changed genetic architecture, increased micronutrient uptake along with appropriate distribution in edible tissues to safe levels, reduction in antinutrients and enhanced bioavailability of nutrients (Prasad et al., 2015). On the other hand, conventional breeding has various disadvantages also in comparison to transgenic approaches. Breeding strategies generally depend on limited genetic variation present in the gene pool which can be overcome by crossing to distant relatives and thus moving the trait slowly into the commercial cultivars upto some extent.

Genetic Engineering and Transgenic Approaches for Biofortification

Genetic engineering (GE) is a very useful technology which can be used for meeting increasing needs of future food, feed and energy. It facilitates vegetable breeders to integrate desired transgenes into elite cultivars thus improving their value and nutritional quality significantly and bringing several health benefits. Several traits like higher nutritional status, slow ripening, better flavor, reduced bitterness, seedless fruit, enhanced sweetness and reduced anti-nutritional factors have been improved in horticultural crops using genetic engineering. Further, nutritional genomic studies which can define the relationship between genomes, nutrition and health are also extensively useful. Rapid development and use of whole-genome sequencing, high throughput physical mapping, global gene expression analysis and metabolite profiling has proved to be helpful in identification and characterization of various genes and their function which ultimately leads to engineer plant metabolism for biofortification (Gupta, 2014). In addition, pathways from bacteria and other organisms can also be integrated into different crops to exploit alternative pathways for metabolic engineering and improving different traits.

Various examples of Biofortification in Horticulture

Recently developed biofortified vegetable genotypes viz; Pusa Beta Kesari 1 (β-carotene rich cauliflower), Bhu Sona (β-carotene rich sweet potato), Bhu Krishna (anthocyanin rich sweet potato) etc. are boon to fight against hidden hunger.

Biofortification of Crops with Zinc

The relationship between foliar Zn application and tuber Zn concentration revealed that a saturation curve was observed and reached to maximum at approx. 30 mg Zn/kg DM at a foliar Zn application rate of 1.08 g/plant. The use of fertilizer "Riverm" during cultivation of sweet pepper, eggplant and tomatoes helped in zinc enrichment. Biofortified vegetables contain 6.60-8.59 % of Zn more than control sample (Yudicheva, 2014).

Selenium Enrichment

Se is found in the major organic form such as selenomethionine, selenocysteine and methylselenocysteine in the Se-enriched plants and more readily available to humans in this form in comparison to inorganic form. Fruits, vegetables and cereals can be supplemented with Se biofortification upto a very good extent. Se has been found in form of Se-methylselenocysteine or glutamyl-Se-methylselenocysteine in onion, garlic and broccoli. Plants can be enriched with selenium by adding Se to soil; foliar or fruit spraying, soaking seeds in Se solution prior to sowing and hydroponic cultivation with Se enriched nutrient solution. Potatoes, peas, carrots, pumpkins, garlic, broccoli, cabbages, radishes, basil, tomatoes, peaches, pears and grapes are some of the examples where Se content has been enhanced using these strategies (Puccinelli et al., 2017).

Iron Biofortification in Leafy Vegetables

Different edible products can be enriched by bioavailable iron using both conventional and transgenic breeding strategies. Identification of iron-rich genotypes among cultivated varieties, collection of diverse germplasm, isolation of underexploited Fe rich leafy vegetables, exploitation of wild relatives and crossing high iron varieties with local varieties can enhance the iron content in several crops. Mutation breeding for improving iron content and transfer of iron-rich gene from other crops or wild relatives through transgenic breeding are also other approached for Fe enrichment. Utilization of molecular markers that are closely linked with the traits of interest may also prove useful in this direction. However, the growing challenges have to be overcome through better understanding of the physiological mechanisms of iron in plant system (Chatterjee et al., 2016).

Biofortification of Provitamin- A Carotenoids

Wide genetic variability exists for pro vitamin A carotenoids in lettuce, carrots, spinach, pumpkin, broccoli, watercress, kale, sweet potatoes, cashews, chicory, cassava, guava, papaya, mango, corn and mustard which may be used for breeding programs, particularly in conventional breeding to get provitamin- A enriched biofortifed crops (Table 2).

Table 2: Variation in carotenoids in different vegetables crops

Vegetable	Components (µg g $^{-1}$)			
	α	β	L	Total carotenoids
Pumpkin	153.8	286.7	1.32	506.6
Sweet potato		291.1		333.4
Carrot	62.2	70.3	5.5	138.0
Cassava		33.4	6.2	56
Corn		4.9	5.5	42.8

Iodine Biofortification in Vegetables

Iodine deficiency may be cured by increasing the iodine level in edible plants by growing vegetables on soils with algal-based iodized organic fertilizer and this is a very effective and innovative approach to proivide iodine supplementation. Silver iodide precipitation technique using microscopy proved the increased biological absorption and migration of iodine within the vegetable plants (Weng et al., 2013).

CONCLUSION

Biofortification offers a good opportunity to malnourished people living in remote rural areas by providing naturally fortified foods as they have limited access to commercially marketed fortified foods in comparison to the people living in urban areas. Eventually, good nutrition relies on proper intake of variety of nutrients and other compounds in appropriate concentration and combinations which should be kept in mind and such things are yet to understand to achieve the complete goals of biofortification. Hence, providing increased supply of a range of non-staple foods may be the best way to eliminate problem of malnutrition from the developing countries. However, this needs many decades, relatively large investment in agricultural research and other public and on-farm infrastructure, precise government policies etc. for proper implementation. A number of conventional and transgenic varieties have been developed and distributed to the farmers and many are in pipeline. But, the efficacy of the biofortification program basically depends on the farmers' and consumers' approval and future policies. Therefore, appropriate and accurate policies and tactical research efforts can lead to biofortification's grand success in the future.

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