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Biofortification of fruits for improved nutritional and postharvest quality

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Abstract

Deficiency of micronutrients and vitamins in human body can lead to diseases, disabilities, stunted physical and mental growth. Biofortification of food crops can be a solution for overcoming problems of malnutrition and hidden hunger. Biofortification is the process of increasing deficient micronutrients in the desirable plant parts through fertilization, breeding and transgenic approach. It is a cost-effective and sustainable approach to provide nutrition to the under-privileged population. Other than biofortification of staple food crops, fruit crops can also be targeted. Fruits are already rich in health promoting substances like vitamins, minerals and antioxidants which are required for proper functioning of human body. Fruits like banana, strawberry, apple, mango, etc. have been biofortified adopting various techniques. The two challenges that are faced in the process of biofortification of fruits are the development of nutrient rich variety and adoption of improved variety by the farmers.

INTRODUCTION

Malnutrition is a major problem faced by majority of people living in developing and under-developed countries. According to the report submitted by FAO along with International Fund for Agricultural Development, and World Food Program on malnutrition in 2015, revealed that 792.5 million people across the world are malnourished, out of which 780 million people belong to developing and under-developed countries (McGuire, 2015). Malnutrition results in several disabilities and diseases in humans. Every year more than five million deaths of children are recorded due to micronutrient malnutrition (WHO, 2015). According to WHO (2015) nutrient malnutrition causes 20 million death per annum, which is much more than deaths caused by any other factors. Ever growing human population, shrinking agricultural lands and lower per capita income of people contributes to the problem of malnutrition. The major micronutrients whose deficiency is predominant among the malnourished unprivileged population is vitamin A, iodine, iron, zinc, folate and selenium. To overcome this situation of under nourishment, food enriched with vitamins, minerals and antioxidants through biofortification is one of the most sustainable and cost effective technique. It allows access to more nutritious foods by the unprivileged population, with the use of fewer resources. Biofortification or biological fortification refers to the process of enhancing nutrient content of the food crops with enhanced bioavailability of the nutrients in the human body using different techniques such as conventional plant breeding, modern biotechnological tools, and agronomic practices.

Fruits, in general are a rich source of macronutrients, micronutrients, vitamins, carbohydrate and antioxidants and also

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contains phytonutrients such as anthocyanins, lycopene, carotenoid, phenolics and ascorbic acid that have the potential to prevent several chronic diseases in human. So, bio-fortification of fruits with a particular deficient or low level of micro-nutrient can help in alleviating the problem of malnutrition to a greater extent along with its other beneficial properties.

BIO-FORTIFICATION STRATEGIES

Bio-fortification of fruit crop can be done in three major ways: agronomic methods, conventional breeding and transgenic developments (Table 1).

Table 1: Biofortification in fruit crops

Crop	Nutrient	Approach	Reference
Banana	Provitamin A	Identification and Selection	Saltzman et al., 2013
	Provitamin A and Iron	Transgenic	Namanya, 2011
	Provitamin A	Transgenic	Waltz, 2014
Apple	Zinc	Fertilization	Zhang et al., 2013
	Resveratrol (antioxidant)	Transgenic	Szankowski et al., 2003
Strawberry	Iodine	Fertilization	Daum et al., 2016
	Selenium	Fertilization	Sánchez-Rodas et al., 2016
Cactus pear	Selenium	Fertilization	Bañuelos et al., 2012
Pear jujube	Selenium	Fertilization	Zhao et al., 2013

Agronomic biofortification

Fertilizer in general is used for increasing the yield of food crops along with fortifying the food crops with macro and micro nutrients. Foliar or soil application of mineral fertilizers was positively correlated with accumulation of nutrients in food crops (Grunes and Allaway, 2008). So, external application of deficient nutrients directly to the plants through application of fertilizer can improve the nutrient status of crop plants. Hence, this method of biofortification is easy, expensive and temporary. Effectiveness of mineral fertilizer application on crop biofortification is limited by a number of factors such as fertilizer type, application method, mineral mobility and its accumulation in plant. Micronutrient such as Fe and Mn can be applied by foliar means while nutrients such as N, Zn, B, Cl, Ni, Mo and Cu can be applied by both techniques for effective biofortification (Dimpka and Bindraban, 2015). The limitation of agronomic biofortification is that it is difficult to target the accumulation of nutrient in desired plant part beside it having negative environmental effect due to more addition of mineral fertilizer to soil and water.

Conventional breeding biofortification

Biofortification of food crops through conventional breeding is more sustainable, cost-effective and publicly more accepted than agronomic or transgenic approach. The pre-requisite for nutrient improvement of crops is the availability of genetic variation within the gene pool of the crop species. After the identification of crop species with enhanced level of vitamins or micronutrients, it is crossed with the recipient parent using appropriate breeding method. The limitation associated with biofortification through conventional breeding is the huge time required for variety development, less variability for desired trait, and linkage drag.

Transgenic biofortification

Biofortification through transgenic development approach comes into the picture when there is absence or limited genetic variation for nutrient content within the gene pool. It involves transfer and expression of desired gene for nutrient enhancement and bioavailability from other species outside the gene pool to the crop plant under improvement. With the advantages of overcoming genetical barriers and requiring less developmental time, its application is limited by the regulatory hurdles and less public acceptance associated with it.

BIOFORTIFIED FRUIT CROPS

Banana

Banana/Plantains is the fourth most important food crop of the world which is also a staple for many Asians and Africans around the globe. It is rich in number of nutrients but low in pro-vitamin A and iron, leading to vitamin A and iron deficiency in the population. So, biofortification of banana and plantain with high level of pro-vitamin and iron would help to solve the problem of malnutrition to a greater extent. Conventional breeding in case of banana is quite difficult and expensive due to its sterile nature of triploids and cross incompatibility, so identification of natural genotypes with high level of vitamin A would be of greater importance. IITA and Bioversity screened banana germplasm in Nigeria, Ivory Coast, Cameroon, Burundi, and DRC and identified varieties providing up to 20 ppm provitamin A.

The planting materials of varieties identified with high provitamin A are being multiplied and distributed among the farmers in Nigeria (Saltzman *et al.,* 2013). Other than identification of natural genotypes, development of transgenics with desired genes can also be a solution to banana biofortification. Queensland University of Technology in collaboration with National Agricultural Research Organization of Uganda employed genetic engineering techniques to develop transgenic bananas with increased level of provitamin A and iron for Uganda (Namanya, 2011). Super Bananas have been developed with a phytoene synthase (PSY2a), isolated from the asupina banana (high level of beta carotene present) by the researchers of Queensland University of Technology (QUT) in Brisbane, Australia (Waltz, 2014).

Mango

Mango is a rich source of β-carotene, vitamin C, and other important antioxidants. All over the world there are varieties developed in mango with enhanced level of β-carotene and vitamin C content to aid the cause of bio-fortification. In India, Indian Agricultural Institute has released many improved hybrids of mango with improved TSS, vitamin C, β-carotene content which includes Mallika, Amrapali, Pusa Peetamber, Pusa Shreshth and Pusa Lalima.

Apple

Apple is a great source of vitamins, nutrients and antioxidants providing healthy life to humans. Agronomic strategy for biofortification of apple with zinc (Zn) was attempted by Zhang *et al.,* (2013) in cultivar Fuji. The fruits were sprayed with Zn at different developmental stages and the results showed that the Zn treatments significantly increased the Zn contents and the reducing sugar in fruits at mature stage, thereby improving the quality of apple fruits (Zhang *et al.,* 2013). To enhance the antioxidant levels in apple fruits, apple was transformed with a stilbene synthase gene from the grape, which led to synthesis of resveratrol in transgenic apple, thereby, expanding the antioxidant capacity (Szankowski *et al.,* 2003).

Grape

Grapes have high mineral content, vitamins C and K, antioxidants and other polyphenolic compounds that offer various health benefits. Nutrient fortification in grapes has been achieved through hybrid breeding. The Indian Agricultural Institute has released an improved hybrid of grape, i.e., Pusa Navrang which contains higher amount of TSS, minerals and antioxidants.

Strawberry

Strawberry fruits are rich in vitamin C, minerals and antioxidants. Biofortification of strawberry has been mainly done through application of fertilizer rich in micronutrients. Daum *et al.,* (2015) studied the effect of iodine enrichment of strawberry through foliar and soil application of potassium iodate fertilizer. It was revealed that soil fertilization resulted in only a relatively small enrichment of iodine in the strawberry fruit. Selenium enrichment through foliar and soil application of the fertilizer was done by Sánchez-Rodas *et al.,* (2015) and it was observed that foliar application of fertilizer was more suitable for Se uptake and biotransformation than soil application.

Cactus pear

Cactus pear (*Opuntia ficus indica*) is known for its therapeutic and medicinal properties due to the presence of phenolic substances, flavonoids, carotenoids and betalains (Feugang et al., 2006). It may help in treating diseases like gastritis, hyperglycemia, atherosclerosis, type II diabetes and cancer and can boost the immune system (Feugang et al., 2006). Bañuelos *et al.,* (2012) analysed Cactus pear fruit (*Opuntia ficus indica*) grown in poor-quality agricultural drainage sediment high in salt, B and selenium (Se) for its nutritional contents and found that cactus pear plants contained nutraceutical qualities and represent a useful anti-carcinogenic Se-enriched chemotherapeutic food crop for providing advanced dietary seleno-pharmacology in order to help fight human diseases.

Pear jujube

Pear jujube contains vitamin C, minerals and phenolics making it nutritious for maintenance of human health. Zhao *et al.,* (2013) obtained selenium fortified jujube (*Zizyphus jujuba*) through soil application, trunk injection or foliar application of sodium selenite and was found that foliar application of Se had higher fruit Se utilization than the other two approaches. Se fortified fruits besides having an increased concentration of selenium along with vitamin C, soluble protein, total soluble sugar, and organic acid content in fruits also enhanced yield of pear-jujube (Zhao *et al.,* 2013).

Polyphenol oxidase (PPO) also referred to as catechol oxidase, tyrosinase, catecholase or o-diphenol oxygen oxidoreductase are copper containing enzymes involved in the oxidation of phenolic compounds and degradation of anthocyanin pigments of litchi pericarp. The enzyme has an optimum pH of 6.5 with temperature optima of 70°C (Jiang *et al.,* 1997; Jiang *et al.,* 1999). PPO is the most crucial enzyme which is associated with the pericarp browning in litchi. Higher activities of this enzyme are present in the tissues like exocarp and upper-mesocarp where browning is noticed first. Presence of higher concentration of PPO in fruits more susceptible to browning as compared to those which are comparatively less susceptible also affirms its involvement in pericarp browning. PPO activity can be inhibited by antioxidants, like glutathione and L- Cysteine, and accelerated by divalent cations, such as Mn^{2+} and Ca^{2+} (Jiang et al., 1998).

CONCLUSION

Biofortification has provided a feasible means of achieving nutritional security for the malnourished unprivileged populations. A number of staple food crops like rice, maize, wheat, pearl millet, lentil, sorghum, cassava, sweet potato, etc., have been biofortified for different deficient micronutrients but only little research have been done to biofortify fruit crops. Not only research in biofortification but it is also important that the biofortified food reaches the unprivileged population.

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