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BIOFORTIFICATION: RAISING THE NUTRIENT VALUE OF CROP

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Around two billion people across the world suffer from a type of hunger known as "hidden hunger," which is caused by an inadequate intake of essential micronutrients in the daily diet despite increased food crop production (Gould, 2017). The green revolution undoubtedly increased the global agricultural production, but sadly the focus for nutrient content remained unattended for a large amount of time, leading to a rapid rise in micronutrient deficiency in major agricultural products like food grains. This has lead to micronutrient malnutrition. Gradually a shift in focus from higher production food crops to nutrient-rich food crops in sufficient quantities is gaining momentum, thereby helping people combat micronutrient malnutrition, especially in poor and developing countries, where diets are dominated by micronutrient-poor staple food crops.

"Biofortification" or "biological fortification" refers to nutritionally enhanced food crops with increased bioavailability to the human population that are developed and grown using modern biotechnology techniques, conventional plant breeding, and agronomic practices. Biofortification of different crop varieties offers a sustainable and long-term solution in providing micronutrient-rich crops to people. Essential micronutrients using biofortified crops are deployed to consumers through traditional practices used by agriculture and food trade which provides a feasible way of reaching undernourished and low income group families with limited access to diverse diets, supplements, and fortified foods. 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 (Bouis, 1999 and Hefferon, 2016). Furthermore, in the next few decades, a major population increase might take place in the developing world and with the changing climatic conditions; achieving food security will pose a greater challenge (Bazuin et al., 2011). Thus, organizations such as the World Health Organization and the Consultative Group on International Agricultural Research (CGIAR) have included the development of nutritionally enhanced high-yielding biofortified crops as one of their main goals (Bouis, 2000).

Approaches to Enhance Nutrient Content

Various avenues currently in practice to achieve nutritional security are non-genetic and genetic approaches. Non-genetic approach constitutes agronomic biofortification, while genetic approaches constitute biofortification through conventional breeding and genetic engineering.

Agronomic Approaches

Agronomic approach includes physical application of nutrients to the soil, their solubilization and mobilization to various parts of the plants, foliar feeding or seed treatment to enrich the edible part of field crops with micronutrients. Apart from NPK, microminerals iron, zinc, copper, manganese, I, Se, Mo, Co, and Ni are usually absorbed from the soil and occurs in the edible portion of certain plants. Agronomic biofortification is simple and inexpensive, but needs special attention in terms of source of nutrient, application method and effects on the environment. These should be applied regularly in every crop season and thus are less cost-effective in some cases. Soil microorganisms like different species of genera *Bacillus*, *Pseudomonas*, *Rhizobium*, *Azotobacter*, etc. can also be utilized to increase the phytoavailability of mineral elements. The N_2-fixing bacteria play an important role in increasing crop productivity in nitrogen limited conditions. Many crops are associated with mycorrhizal fungi that can release organic acids, siderophores, and enzymes capable of degrading organic compounds and increasing mineral concentrations in edible produce.

Conventional Breeding Approach

Traditional plant breeding includes identifying and developing parent lines with a naturally high concentration of the target nutrient and crossing them over time to produce the desired concentrations of the nutrient and agronomic traits in the plants. Biofortification through conventional breeding in the most accepted method of biofortification. It offers a sustainable, cost-effective alternative to transgenic and agronomic-based strategies. Sufficient genotypic variation in the trait of interest is necessary for conventional breeding to be feasible. Breeding programs can utilize this variation to improve the levels of minerals and vitamins in crops. However, breeding strategies have to sometimes rely on the limited genetic variation present in the gene pool. In some cases, this can be overcome by crossing to distant relatives and thus moving the trait slowly into the commercial cultivars. Alternatively, new traits can be introduced directly into commercial varieties by mutagenesis. For biofortification using the conventional plant breeding approach to be considered as a feasible and effective approach to alleviating hidden hunger, three conditions should be met. These are (1) conventional breeding can add extra nutrients in the crops without reducing yields; (2) when consumed, the increase in nutrient levels can make a measurable and significant impact on human nutrition; and (3) farmers are willing to grow biofortified crops and consumers to eat them.

Biotechnological Approach

Transgenic approach for biofortification is necessary due to several weaknesses of conventional approaches which involve absence of elite genotype for the desired trait within the species (e.g., provitamin A in rice), long time period required to introduce single or multiple traits (pyramiding traits) and inability to target nutritional traits to specific organs. The existence of an inverse relationship between grain mineral concentration and grain yield also limits the application of conventional breeding.

The transgenic approach involves the syntheses of transgenes that causes the micronutrient re-translocation between tissues and enhance their bioavailability, increasing the efficacy and reconstruction of biochemical pathways. It can also be used for reduction in the concentration of antinutrients which limit the bioavailability of nutrients in plants. Among micronutrients, vitamins, minerals, essential amino acids, and essential fatty acids have been targeted by the use of various genes from different sources to enhance the food crop nutritional level. Development of transgenically biofortified crops initially involves substantial amount of time, efforts, and investment during research and development stage, but in a long run, it is a cost-effective and sustainable approach, unlike nutrition-based organizational and agronomic biofortification programs (Hefferon, 2016 and White and Broadley, 2005).

Table 1: Crops biofortified using various approaches

	Crop	Biofortified for	Reference
1	Rice	Beta-carotene	Ye et al. (2000)
		Folate (vitamin B9)	Storozhenko et al. (2007)
		Iron	Takahashi et al. (2001); He et al. (2013)
		Zinc	Wei et al. (2012) CIAT, HarvestPlus
2	Wheat	Zinc	CIAT, CIMMYT, HarvestPlus
		Provitamin A Carotenoids	Wang et al. (2014)
		Iron	Sui et al. (2012); Aciksoz et al. (2011)
		Zinc and iron	Indian Institute of Wheat and Barley Research, India
		Carotene	IARI
		Anthocyanins (colored wheat)	Garg et al. (2016)
3	Maize	Lysine and Tryptophan	SurinderVasal and Evangelina Villegas, CIMMYT
		Provitamin A Carotenoids	Aluru et al. (2008)
		Lysine	Monsanto
		Zinc	Alvarez and Rico (2003)
4	Barley	Zinc	Ramesh et al. (2004)
5	Sorghum	Provitamin A	Lipkie et al. (2013)
		Mycorrhiza + Bacteria	Dhawi et al. (2015)
		Iron	ICRISAT, HarvestPlus
6	Potato	Reduced amylose and increased amylopectin in starch granules	BASF
		Zinc	White et al. (2001)
		Antioxidants	Lachman, et al. (2005)
7	Cassava	Beta-carotene	Biocassava Plus
8	Linseed/flax	Essential amino acids	University of Saskatchewan, Canada
9	Canola	Phytate degradation (increase in available P)	BASF
10	Millets	Iron and zinc(Pearl Millet)	ICRISAT, HarvestPlus
11	Cowpea	Iron	G.B. Pant Agriculture University, HarvestPlus
12	Cauliflower	Beta-carotene	IARI, India
13	Banana	Vitamin A	Bioversity International—Uganda, HarvestPlus
14	Mango	Beta-carotene	IARI, India

Table 2: Significant improvement achieved in nutritional quality over the baseline values and national level released bio fortified variety in different field and horticultural crops (Source: Yadav at al. 2020)

S. No.	Crop	Nutrient	Baseline levels	Levels achieved	national level released bio fortified variety
1	Rice	Protein	7.0-8.0 %	>10.0 %	CR Dhan 310, DRR Dhan 45, DRR Dhan 48, DRR Dhan 49, Zinco Rice MS, CR Dhan 311 (Mukul), CR Dhan 315
		Zinc	12.0-16.0 ppm	>20.0 ppm	
		Protein	8-10 %	>12.0 %	
2	Wheat	Iron	28.0-32.0 ppm	>38.0 ppm	**Bred Wheat**-WB 02, HPBW 01, durum, PusaUjala (HI 1605), HD 3171, PBW 752, PBW 757, Karan Vandana (DBW 187), DBW 173, UAS 375, DDW 47, PBW 771, HD 3298, HI 1633, DBW 303, **Durum**- (DDW 48, PusaTejas (HI 8759), HI 8777, MACS 4028, 4058 & HI 8802, 8805),
		Zinc	30.0-32.0 ppm	>37.0 ppm	
3	Maize	Provitamin-A	0.5-1.5 ppm	>5.0 ppm	**Hybrid**-Vivek QPM 9, Pusa HM4, Pusa HM8, Pusa HM9, PusaVivek QPM9,Pusa VH 27, Pusa HQPM 5, Pusa HQPM 7, IQMH 201, IQMH 202, IQMH 203
		Lysine	1.5-2.0 %	>2.5 %	
		Tryptophan	0.3-0.4 %	>0.6 %	
4	Pearl Millet	Iron	45.0-50.0 ppm	>70.0 ppm	**Hybrid**-HHB 299, AHB 1200Fe, AHB 1269Fe, ABV 04, PhuleMahashakti, RHB 233, : RHB 234, HHB 311
		Zinc	30.0-35.0 ppm	>40.0 ppm	
5	Finger Millet	Iron	25.0 ppm	>38.0 ppm	VR 929 (Vegavathi), CFMV1 (Indravati), CFMV 2
		Zinc	16.0 ppm	>24.0 ppm	
		Calcium	200.0 mg/100g	>400.0 mg/100g	
6	Lentil	Iron	45.0-50.0 ppm	>62.0 ppm	PusaAgetiMasoor, IPL 220
		Zinc	35.0-40.0 ppm	>50.0 ppm	
7	Groundnut	Oleic acid	45.0-52.0	% >70.0 %	Girnar 4, Girnar 5
8	Cauliflower	Provitamin-A	Negligible	>8.0 ppm	Pusa Beta Kesari 1
9	Potato	Anthocyanin	Negligible	>0.60 ppm	KufriManik, KufriNeelkanth
10	Sweet	Provitamin-A	2.0-3.0	>13.0	BhuSona, Bhu Krishna

	Potato		mg/100 g	mg/100 g	
		Anthocyanin	Negligible	>80.0 mg/100g	
11	Greater Yam	Anthocyanin	Negligibl	35-60 mg/100g	SreeNeelima, Da 340,
		Iron	70-120 ppm	>135.0 ppm	
		Zinc	22-32 ppm	>48.0 ppm	
		Calcium	800-1200	ppm >1800 ppm	
12	Pomegranate	Iron	2.7-3.2 mg/100g	>5.0 mg/100g	Solapur Lal
		Zinc	0.50-0.54 mg/100g	>0.6 mg/100g	
		Vitamin-C	14.2-14.6 mg/100g	>19.0 mg/100g	
13	Mustard	Erucic acid	>40.0 %	<2.0 %	Pusa Mustard 30, 31 &Pusa Double Zero Mustard 31
		Glucosinolates	>120.0 ppm	<30.0%	
14	Soybean	Kunitz trypsin inhibitor	30-45 mg/g of seed meal	Negligible	NRC 127, 132,147

Conclusions and Future Thrust

It is well established that biofortification is a promising, cost-effective, agricultural strategy for improving the nutritional status of malnourished populations throughout the world. Biofortification strategies based on crop breeding, targeted genetic manipulation, and/or the application of mineral fertilizers hold great potential for addressing mineral malnutrition in humans. The next gene revolution should focus on sustainable solutions for malnutrition, as part of a humanitarian intervention, concerted with educational efforts as a cornerstone to halt population growth, improve living standards, and bring about global peace.

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