Biofortification to Improve Nutrition: Short Communication

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Abstract :

Biofortification is a promising, economical, and sustainable technique of providing micronutrients. It primarily targets population that has mainly dependent upon major food crops which are unfortunately poor sources of micronutrients. In developing countries, more than 20 million farm families are now growing and consuming biofortified crops. Biofortification research based on different nutrient, different strategies and conducted on different crops. Address advantages and disadvantages of Biofortification and quote that besides challenges biofortified crop embrace bright future to challenge malnutrition.

Keywords : Biofortification, Nutrition, Transgenic, Agronomic, Genetic modification, Micronutrients

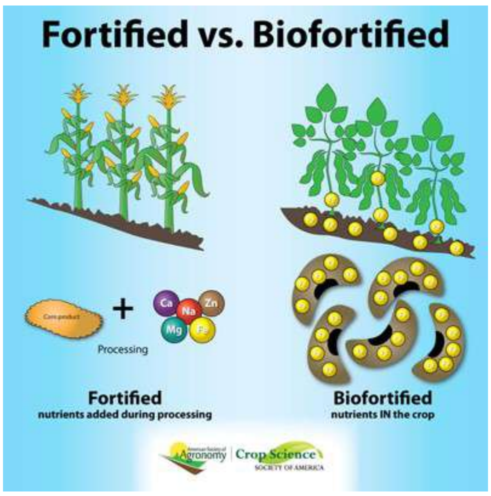
Introduction

Bio fortification is the process of adding nutritional value to the crop. It refers to nutrient enrichment of crops to address the negative economic and health consequences of vitamin and mineral deficiencies in humans. Bio-fortification, the process of breeding nutrients into food crops, provides a comparatively cost-effective, sustainable, and long-term means of delivering more micronutrients. The approach not only will lower the number of severely malnourished people who require treatment by complementary interventions but also will help them maintain improved nutritional status. The term "hidden hunger" has been used to describe the micronutrient malnutrition inherent in human diets that are adequate in calories but lack vitamins and/or mineral elements. The diets of a large proportion of the world's population are deficient in Fe, Zn, Ca, Mg, Cu, Se, or I, which affects human health and longevity and therefore national economies. Mineral malnutrition can be addressed by increasing the amount of fish and animal products in diets, mineral supplementation, and food fortification and/or increasing the bioavailability of mineral elements in edible crops. However, strategies to increase dietary diversification, mineral supplementation, and food fortification have not always proved successful. For this reason, the biofortification of crops through the application of mineral fertilizers, combined with breeding varieties with an increased ability to acquire mineral elements, has been advocated [1]

Discussion :

Food Fortfication And Supplementation:

Is currently the most cost-effective strategies to address global mineral malnutrition. The most successful strategy has been salt iodization (fortification with iodine) which has reduced the incidence of goiter and other IDD symptoms markedly where the scheme has been introduced.[2]



Need of Bio-Fortification:

The world population was continuously increasing; suffer from lack of food, so that fighting hunger continues to be a challenge for humanity. On the other hand, the world health organisation estimates that, worldwide, 1.5 billion people are overweight (WHO 2011). Increasingly these two forms of malnutrition, underweight and overweight are occurring simultaneously with in the countries. Vitamin A deficiency (VAD) is an important health concern in developing countries among children and women of childbearing age and is estimated to account for > 600,000 deaths each year globally among children <5 years of age. According to Government of India statistics provided to the World Health Organization (WHO) 62% of all preschool-age children are VAD. Iron (Fe), zinc (Zn), and selenium (Se) deficiencies are serious public health issues and important soil constraints to crop production, particularly in the developing countries.

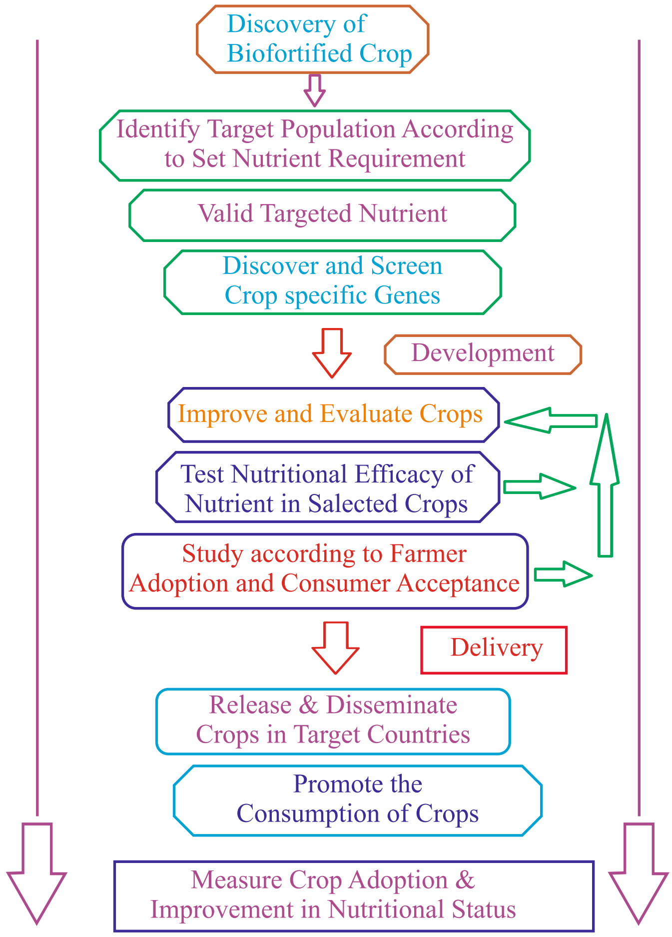
Present Status of Biofortification In India :

Indian Council of Agricultural Research, National Research Institutions and State Agricultural Universities has improved the nutritional quality in high yielding varieties of cereals, pulses, oilseeds, vegetables and fruits using different conventional and advanced breeding methods[3]. Biofortification special efforts were initiated during 12th Plan of ICAR with the launching of a special project on Consortium Research Platform on Biofortification in selected crops for nutritional security during 2010s. Concerted efforts in collaboration with other national and international initiatives has led to the development of 71 biofortified varieties (Table - 1) of wheat, maize, pearl millet, rice, finger millet, mustard, soybean, lentil, groundnut, potato, sweet potato, greater yam, small millet, linseed, cauliflower and pomegranate. The maximum number of biofortified varieties developed in wheat followed by maize, pearlmillet and rice (Fig. 1) while trait wise improvement of essential nutrients maximum for iron followed by zinc, protein, lysine, tryptophan and so on (Fig. 2). In addition, a large number of advance elite materials are in pipelines and will be released in due course of time. These biofortified varieties assume great significance to achieve nutritional security of the country. Special efforts are being made to popularize these biofortified varieties among masses. Quality seeds of biofortified varieties are being produced and made available for commercial cultivation. Extension Division of ICAR has also launched two special programmes viz. Nutri-sensitive Agricultural Resources and Innovations (NARI) and Value Addition and Technology Incubation Centres in Agriculture (VATICA) for up-scaling the biofortified varieties through its Krishi Vigyan Kendras (KVKs). The other agencies like DBT, ICMR, HarvestPlus and CSIR also continuously working on different projects for development of biofortified staple food.

S. No.	Crop	Biofortified Traits	Biofortified Varieties	Characterstics
1.	Rice	High Protein	CR Dhan -310	10.3% protein (~2% more than popular varieties)
		Zinc content	DRR Dhan - 45, DRR Dhan – 48, DRR Dhan – 49, Zinco Rice MS & CR Dhan – 315	~24 PPM (~ 10 PPM more than popular varieties)
		High protein & Zinc	CR Dhan – 311	10.2% protein and 20 PPM Zn
2	Wheat	Iron	HD – 3249 & DBW -187,	42 PPM Fe (~10 PPM more)
		Zinc	PBW – 771, PBW – 757 & HD – 3171	42 PPM Zn (~10 PPM more)
		Protein	DDW -48 (Durum), DBW-303, HI -8802 (Durum), UAS – 375 & PBW – 752,	12.5 % protein (~2% more than popular varieties)
		Iron & Zinc	HI – 8777 (Durum), HPBW -01, WB –02,	48 PPM Fe & 43 PPM Zn
		Iron, Zinc & Protein	HI – 1633, MACS - 4058 (Durum), MACS – 4028 (Durum) & HI – 8759 (Durum),	40.6 PPM Fe, 40.1 PPM Zn and 12.4%protein,
		Protein & Iron	HD – 3298, HI- 8805 (Durum), DDW – 47 (Durum), DBW – 173 & HI -1605,	12.8% protein & 40 PPM Fe

3.	Maize	Lysine & Tryptophan	Vivek QPM – 9, Pusa HM – 4 Improved, Pusa HM8 Improved, Pusa Hm9	4.19 % lysine & 0.83% tryptophan (2x as compared to popular cultivars)
			Improved, IQMH – 201, 202 & 203.	
		Provitamin - A	Pusa VH – 27 improved	5.49 PPM Provitamin – A
		Provitamin – A, Lysine & Tryptophan	Pusa Vivek QPM9 Improved Pusa HQPM - 5 Improved & Pusa HQPM - 7 Improved	8.15 PPM provitamin – A, 2.67 % lysine and 0.74% tryptophan
4.	Pearlmillet	Iron	HHB – 311 & AHB – 1200Fe,	83 PPM Fe (~40 PPM more than popular cultivars
		Iron & Zinc	HHB - 299, RHB - 234, RHB -233,Phule Mahashakti, ABV 04 & AHV – 1269Fe	83 PPM Fe & 45 PPM Zn
5.	Finger Millet	Iron	VR 929 (Vegavathi)	131.8 PPM Iron (~ 100 PPM more than popular cultivars
		Calcium, Iron & Zinc	CFMV – 1 (Indravati), CFMV – 2	Rich in Ca (428mg/100g), 58 PPM Fe & 44 PPM Zn
6.	Lentil	Iron	Pusa Ageti Masoor	65 PPM Fe (~ 20 PPM more than popular cultivars)
		Iron & Zinc	IPL – 220	73 PPM Fe & 51 PPM Zn
7.	Groundnut	Oleic acid	Girnar – 4 & Girnar – 5	78.5% oleic acid (~30% more in comparison to popular cultivars)
8.	Little millet	Iron & Zinc	CLMV – 1	59 PPM Fe & 35 PPM Zn
9.	Linseed	Linoleic acid	TL 99	58.9% Linoleic acid (~35% more as compare to popular cultivars)
10.	Mustard	Erucic acid*	Pusa Mustard – 30, Pusa Mustard – 32,	1.20% Erucic Acid (~40% less as compareto popular cultivars)
		Erucic Acid* & Glucosinolates*	Pusa Double Zero Mustard – 31	Low erucic (0.76%) & Low glucosinolates (29.41 PPM)
11	Soybean	Kuntiz Trypsin Inhibitor Free	NRC – 127	Free from Kuntiz Trypsin Inhibitor (30-40 mg/g of seed meal in popular varieties)
		Lipooxigenase – 2 free	NRC – 132	Free from Lipooxigenase -2
		Oleic acid	NRC – 147	High Oleic acid (42%) as compare to popular cultivars (25%).
12.	Cauliflower	Provitamin - A	Pusa Beta Kesari 1	10 PPM Provitamin – A (negligible inpopular cultivars)
13.	Pomeg-ranate	Iron, Zinc & Vitamin - C	Solapur Lal	Rich in iron (5.6-6.1 mg/100g), zinc (0.64- 0.69 mg/100g) and vitamin-C (19.4-19.8 mg/100 g) in fresh arils
14.	Potato	Anthocyanin	Kufri Manik, Kufri Neelkanth	0.88 PPM Anthocyanin (negligible in popular cultivars)
15.	Sweet Potato	Provitamin - A	Bhu Sona	14.0 mg/100g Provitamin-A (as comparison to 2.0-3.0 mg/100g in popular varieties)
		Anthocyanin	Bhu Krishna	90.0 mg/100g Anthocyanin (negligible amount in popular varieties)
16.	Greater Yam	Anthocyanin, Protein & Zinc	Sree Neelima	50.0 mg/100g Anthocyanin, 15.4 % crude protein and 49.8 PPM zinc
		Anthocyanin Iron & Calcium	Da 340	Rich in Anthocyanin (141.4 mg/100g), iron (136.2 ppm) and calcium (1890 ppm)

Path Way of Bio Fortification:



Methods of Bio Fortification:

Plant Breeding: Plant breeding programs focus on improving the level and bioavailability of minerals in staple crops using their natural genetic variation[(4)]. Breeding approaches include the discovery of genetic variation affecting heritable mineral traits, checking their stability under different conditions, and the feasibility of breeding for increasing mineral content in edible tissues without affecting yields or other quality traits. Breeding for increased mineral levels has several advantages over conventional interventions (e.g., sustainability); no high mineral varieties produced by this method have been introduced onto the market thus far. This reflects long development times, particularly if the mineral trait needs to be introgressed from a wild relative. Breeders utilize molecular biology techniques such as quantitative trait locus (QTL) maps and marker-assisted selection (MAS) to accelerate the identification of high-mineral varieties, but they have to take into account differences in soil properties (e.g., pH, organic composition) that may interfere with mineral uptake and accumulation. For example, the mineral pool available to plant roots may be extremely low in dry, alkaline soils with a low organic content[(5)].

Conventional Plant Breeding:

Conventional breeding is limited, however, because it can only use the genetic variability already available and observable in the crop being improved or occasionally in the wild varieties that can cross with the crop. Furthermore, conventional breeders usually have to trade away yield and sometimes grain quality to obtain higher levels of nutrition. 1. Quality protein maize (QPM), which has taken decades of conventional plant breeding work to develop into varieties acceptable to farmers. However, multiple gains are at times possible, as with iron and zinc in rice and wheat, where the characteristics that lead to more iron and zinc in the plant can also lead, by some accounts, to higher yield. 2. Orange-fleshed sweet potatoes (OFSP) promoted through the Harvest Plus program in Africa, have been successfully selected and developed for both nutrient and (at least rainy season) yield traits[(6)].

Mutation Breeding:

Mutation breeding has been used extensively in developed and developing countries to develop grain varieties with improved grain quality and in some cases higher yield and other traits. This technique makes use of the greater genetic variability that can be created by inducing mutations with chemical treatments or irradiation. Varieties generated using mutagenesis may be cultivated and certified as organic crops in the United States, while transgenic crops created with recombinant DNA (rDNA) technology are prohibited from such certification.

Agronomic Bio Fortification:

Application of fertilizers to increase the micronutrients in edible parts. The degree of success in agronomic bio fortification is proportional to the mobility of mineral element in the soil as well as in the plant[7]. Most suitable micronutrients for agronomic bio fortification Zinc, (foliar applications of $ZnSo_4$), Iodine(Soil application of iodide or iodate), Selenium(as selenate). The application of inorganic Se fertilizers resulted in over 10-fold increase in Se concentrations .The use of inorganic I and Zn also had an impact on plant enrichment at a country scale in China and Thailand. Fe ($FeSO_4$) shows a low mobility in soil due to conversion of Fe+3 which is unavailable to plant roots. Bottleneck of Phytoavailability, to overcome this, Synthetic metal chelators (e.g. EDTA- Fe- and Zn-chelates which were effective in increasing mineral concentration in edible vegetable and fruit tissues (Shuman 1998 -5). (8) Foliar application is the quick and easy method of nutrient application to fortification of micro nutrients (Fe, Zn, cu etc.) in plants. Several studies have found that the mycorrhizal associations increase Fe, Se, Zn and Cu concentrations in crop plants[9]. AM-fungi increases the uptake and efficiency of micronutrients like Zn, Cu, Fe etc.

Biofortification of Crops With Iron

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 programs. The fruit concentration of iodine detected in 5 mM iodide–treated plants was more than enough to cover a daily human intake of 150 µg[10] Increasing iron levels of Amaranthus plants by using S.platensis as microbial inoculant when compared with control and he also reported that Spirulina platensis has been used as biofortifying agent to enhance the iron status in Amaranthus gangeticus plant [11].

Biofortification of Crops With Zinc

The relationship between tuber Zn concentration and foliar Zn application followed a saturation curve, reaching a maximum at approx. 30 mg Zn kg–1 DM at a foliar Zn application rate of 1.08 g plant–1. Despite a 40-fold increase in shoot Zn concentration compared to the unfertilised controls following foliar Zn fertilisation with 2.16 g Zn plant–1 [White, P.J., 2009]. The use of fertilizer "Riverm" during cultivation of sweet pepper, eggplant and tomatoes helps to be enriched by zinc. Biofortified vegetables contain 6.60-8.59 % of Zn more than control [12].

Biofortification of Crops With Selenium

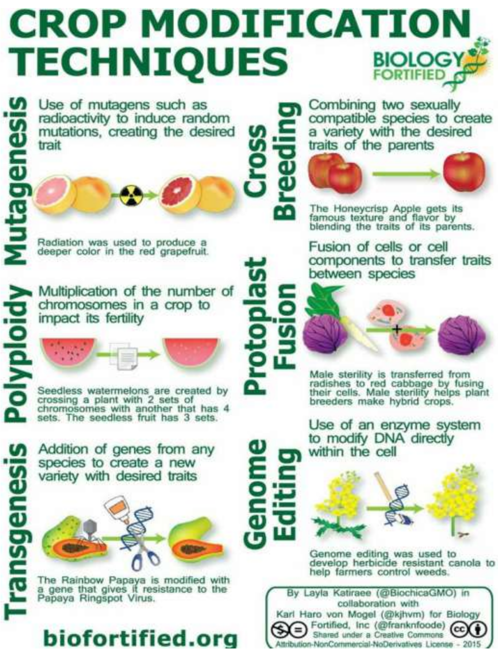
Se-enriched S. pinnata is valuable as a soil amendment for enriching broccoli and carrots with healthful forms of organic-Se. Onions and carrots were bio-fortified by foliar application of a solution of 77Se(IV) that was enriched to 99.7% as 77Se [13]. In brassica vegetables selenium application did not affect the yield or oil content [Kapolna Emese,2012]. High accumulation of Se in the seeds and meal of (1.92–1.96 µg Se g−1) was detected[14].

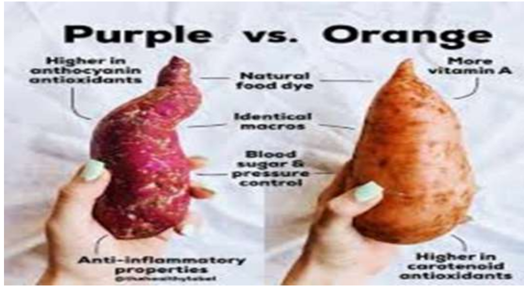
Molecular Breeding:

Marker-assisted breeding, This is a powerful tool of modern biotechnology that encounters little cultural or regulatory resistance and has been embraced so far even by organic growers because it relies on biological breeding processes rather than engineered gene insertions to change the DNA of plants. The use of molecular breeding has increased dramatically both by private seed companies and government plant breeders in developed countries, and it is gradually spreading to developing countries (Pray 2006). [15] Using this technique, plant breeders also can stack into one variety several different genes that code for different traits, for example, QPM, disease resistance, and drought tolerance in maize (Pray 2006).[15] The technique has also been used to find recessive traits in plants that cannot be located by conventional breeding or other techniques.

Genetic Engineering:

Genetic engineering is the latest weapon in the armory against mineral deficiency and uses advanced biotechnology techniques to introduce genes directly into breeding varieties. The genes can come from any source (including animals and microbes) and are designed to achieve one or more of the following goals : (a) Improve the efficiency with which minerals are mobilized in the soil. (b) Reduce the level of anti- nutritional compounds. (c) Increase the level of nutritional enhancer compounds such as inulin[16].





EXAMPLES OF BIO FORTIFICATION: [17]

Biofortified crop	Target micronutrient	Country where crop has been trialled
Orange sweet potato	Vitamin A	Uganda; Zambia
Beans	Iron	Uganda; Zimbabwe; Rwanda
Cassava	Vitamin A	Nigeria; Democratic Republic of Congo; Kenya
Maize	Vitamin A	Nigeria; Democratic Republic of Congo; Zambia; Zimbabwe
Pearl millet	Iron	India
Wheat	Zinc	India; Pakistan
Rice	Zinc	Bangladesh

Orange Sweet Potato (osp):

To increase targeted level of 30 ppm of provitamin A in sweet potato, International Potato Centre (CIP) in south Africa and Uganda(Harvest plus) + National agriculture Research and Extension System (NARES) started project in 2002-2007 and the first variety released in 2002. This variety have ability to grater provitamin A retention more than 80% after boiling or steaming and at least 75% after solar or sun drying but also high yielding and drought tolerant. Harvest Plus and its partners distributed OSP to more than 24,000 households in Uganda and Mozambique. Bio fortified varieties are now being introduced in many parts of Africa and South America, as well as China. In 2009, CIP launched its Sweet Potato for Profit and Health Initiative (SPHI), which seeks to deliver OSP to 10 million households in Africa by 2020.

Bio Cassava:

Projecton Bio Cassava Plus initiative started in 2009 by Donald Danforth Plant Science Center to target Nigeria, Kenya with 6 major objectives namely to increase the minerals zinc and iron, vitamins A and E, protein contents and decrease cyanogen content, delay postharvest deterioration, and develop virus- resistant varieties. The scientists have developed three new yellow colour varieties of cassava by hybridization and selective breeding methods. The varieties can produce higher amount of beta-carotene which helps to fight against vitamin A malnourishment in the region and release of the varieties will be in 2017.

Potato:

CIP (International centre for potato) started project on development of Fe rich potatoes by conventional bio fortification method in 2009 and the varieties was be release in 2017. Cow pea Pioneer research on biofortifcation of cow pea has initiated G.B. Pant University of Agriculture and Technology, Pantnagar, India. Two early maturing high iron and zinc fortified varieties namely Pant Lobia-1(82ppm Fe and 40ppm Zn), Pant Lobia-2(100ppm Fe and 37 ppm Zn) has been developed by conventional plant breeding and released in 2008 and 2010.Pant Lobia-3 (67 ppm Fe and 38 ppm Zn), Pant Lobia-4(51ppm Fe and 36 ppm Zn) released in 2013 and 2014 respectively. Brazil also released three varieties of high-iron cowpeas, developed by Embrapa, in 2008 and 2009 and bio availability.

Nutri Banana:

Breeding banana/plantain (Musa) is complex, as commercial varieties are sterile triploids (3X). Among the fertile groups, a high degree of cross incompatibility can exist. Further, the Musa crop cycle is long. Genetic engineering method of bio fortification is suitable for banana because most of the edible bananas are vegetative propagated and transgene outflow are minimum and therefore genetically modified bananas can be grown alongside non-GM bananas in the same field. Also since the GM bananas are sterile, the existing diversity of bananas in India will not be affected and there won't be any heritable mixing of GM and non GM cultivars in nature. Unfortified bananas have 0.4 mg/100 gm Fe of banana while the fortified banana would supplement this to 2.6 mg/ 100 grams .The bio fortification of banana by increasing their beta carotene (up to 20ppm), alpha tocopherol and iron content. Bio fortification works on banana will be beneficial where bananas are the major staple food source and good consumer acceptance. The bio fortification works on banana had been initiated at Queensland University of Technology (QUT), Australia to develop pro-vitamin A (βcarotene), alfa tocopherol and iron rich varieties besides they succeed in improving the disease resistant varieties against Banana Bunchy Top Virus (BBTV) and Fusarium Wilt. These varieties are under field and selection for enhanced level of micronutrients that may match pro vitamin A (PVA) and iron requirements is desirable for India. Works initiated to transfer of specific traits in two Indian banana varieties cv. Grand Nain and Rasthali. Donald Danforth Plant Science Centre working on nutribanana to develop 20 ppm pro-vitamin.

Beans:

Irn (Fe) content in common bean is about 50 parts per million (ppm) and target in bio fortification of bean by conventional breeding is 94 ppm, bio fortified beans provide about 60% of the Estimated Average Requirement (EAR). Non-bio fortified beans produce approximately 0.8 tons/hectare (bush and climbers combined) but bio fortified bush beans yield around 1.5 t/ha and biofortified climber beans 2–3 t/ha. Among the different varieties released in Rwanda in 2012 and 2014 MAC-42 from CIT contains 91ppm iron and ability to resistance against anthracnose and bean common mosaic virus and ability to produce 3.5t/ha.

Conclusion:

Bio fortified crops, either by conventional breeding methods or by modern biotechnological tools, are not a solution for malnourishment. The ultimate aim in global nutrition remains a sufficient and diverse diet for the world's population. However, bio fortified crops can complement existing micronutrients interventions; can have a significant impact on the lives and health of millions of people, especially those most in need.

Future Challenges:

Produce crops for human nutrition with increased iron concentration. Biofortification strategies alternative to reduction in concentration of phytic acid or polyphenols should be explored further, in order to increase iron absorption without loss of their beneficial effects. When overexpressing ferritin, such crops should be tested for concentration of various heavy metals, in laboratory as in open-field trials, before releasing to the public. Detailed knowledge on mechanisms regulating iron compartmentalization in various plant organs will offer a major contribution for reaching such goal.

Source of Support: Nil

Conflict of Interest: Nil

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