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Biofortification: A sustainable way for checking malnutrition to Iron and Zinc

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Abstract
According to World Bank, India loses over $12 billion annually in GDP to vitamin and mineral deficiencies. Iron deficiency is the sixth most serious problem for human health. In India alone, about 80% of the pregnant women, 52% of non-pregnant women, and 74% of children in the 6-35 months age group suffer from iron deficiency. About 52% of children below 5 year are zinc deficient. Malnutrition is a serious health issue in India, and to realize India free from malnutrition ‘‘Kuposhan Mukt Bharat’’ by 2022. Production of iron and zinc enriched food crops by biofortification has a great potential to combat this problem.

Keywords: Biofortification, malnutrition, zinc, iron

Introduction
Human body require food consisting of carbohydrate, fats, protiens, vitamins and minerals. The essential mineral elements like Fe, Zn and I are most frequently lacking in human diets than other elements like Ca, Mg, Cu and Se are also deficient in some population (Welch and Graham, 2004; Frossard *et al*., 2000; Grusak MA and Cakmak I, 2005) [1, 3]. However, iodine requirement can be fulfilled by iodised salt. It is estimated that world’s 60–80% are Fe deficient and more than 30% are Zn deficient (Kennedy *et al*., 2003; Hotz and Brown, 2004; Stein, 2010) [4-6] WHO estimated that around the world one-third are anemic at reproductive stage but in South Asia, 88% of the pregnant women are anemic (IRRI, 2006) [7], where cereal are staple food and cases of micronutrients malnutrition is the highest due to cereal–cereal crop rotations. Hence, mineral nutrition security should be taken care as top public health priority (Welch and Graham, 2004; Pooniya *et al*., 2012; Shivay *et al*., 2016) [1, 8, 9]. Additionally, poor masses of population of developing countries like India, Bangladesh and Manammar can’t effort available nutritional supplements of Zn and Fe (Prasad *et al*., 2014) [10] and improving dietary composition (consuming more meat, fruits, and green vegetables) which are costly. Hence, biofortification is only way to make available essential minerals and vitamins at effective cost through their staple food up to the poorest society. Enhanced nutritional quality of crops through agronomic intervention or genetic selection by enabling the plant to synthesize more vitamins or to take up minerals with greater efficiency from the soil (Raboy, 2002; Bouis *et al*., 2003) [11, 12].

Zn requirement in Human Body
Zinc is among one of essential mineral nutrient which requires in more than 300 enzymes (Palmgren *et al*., 2008) [13] and hormones metabolism. It plays critical role in many organs like teeth, skin, bones, nerves, brain and sexual maturation. Most abundant source of Zn are meat-based products and other sources are mushrooms, hazelnut, cabbage, dates black, sesame, edible fungus. Most commonly eaten farm products are poor source of Zn like cereals, pulses, vegetables and fruits. Based on appearing of sign and symptoms Recommended Daily Intake (RDI) estimated (Table 1).

Table 1: Zinc Daily Reference Intakes requirements

Infants		Pregnancy	
0-6 months	2 (mg/day)	<18 years	13 (mg/day)
7-12 months	3 (mg/day)	19-50 years	11 (mg/day)
Children		Lactation	
1-3 years	3 (mg/day)	<18 years	14 (mg/day)
4-8 years	5 (mg/day)	18- 50 years	12 (mg/day)
Males		Females	
9-13 years	8 (mg/day)	9-13 years	8 (mg/day)
14-70 <years	11 (mg/day)	14-18 years	9 (mg/day)
		19-70< years	8 (mg/day)

(Bhowmik *et al*., 2010) [14].

Iron requirement in Human Body

Anaemia occurrence in developed countries are lower than developing countries. Iron (Fe) has vital role in various metabolic processes viz. deoxyribonucleic acid synthesis and electron transport (Abbaspour *et al*., 2014) [15]. Additionally, iron is integral part of haemoglobin and myoglobin which transport oxygen, involved in oxidation-reductions (Hurrell, 1997; McDowell, 2003) [16, 17]. Iron deficiency direct problems in cognitive growth, infection resistivity, productivity of work of pregnancy women (Mayer *et al*. 2008) [18]. Reproductive aged women are most vulnerable to anaemia with an estimate of 44% in developing countries (Haas *et al*. 2005) [19]. This cause more iron deficient children. Due to low iron reserves in children of iron deficient mother, cause risk of growth impairment which can be prohibited by supplying more iron by breast milk (WHO 2001) [20]. According to the Food and Nutrition Board of the Institute of Medicine, the daily reference intake requirements are given in Table 2.

Table 2: Iron Daily Reference Intakes requirements

Infants		**Pregnancy**	
0-6 months	0.27 (mg/day)	14-18 years	23 (mg/day)
7-12 months	11 (mg/day)	19-50 years	22 (mg/day)
Children		Lactation	
1-3 years	07 (mg/day)	14-18 years	10 (mg/day)
4-8 years	10 (mg/day)	19-50 years	09 (mg/day)
Males		**Females**	
9-13 years	08 (mg/day)	9-13 years	08 (mg/day)
14-18years	11 (mg/day)	14-18 years	15 (mg/day)
19- 70 <years	08 (mg/day)	19- 50 years	18 (mg/day)
		50-70< years	08 (mg/day)

(Institute of Medicine, 2001) [21].

Biofortification

Fortification can be done by two means by taking mineral supplements which is most common among high society community and by biofortification which is sustainable for long term rural poor society population. Biofortification is the process of increasing the bioavailable concentrations of essential elements in crops through agricultural interventions by agronomic intervention or genetic manipulation or conventional breeding.

Approaches of biofortification

Agronomic intervention

During the crop production, appropriate application and management of Zn and Fe nutrient in the soil either though inorganic fertilizer or organic source increases the mineral content of the plant by uptake as demonstrated successfully in different crops like rice, wheat and maize (Bouis *et al*., 2010) [22]. However, utilization and uptake of Zn and Fe differ among crops and variety as well. Meanwhile, field nutrient management is diversified according to climate and ecological situation. Situation where fertilizers are not effective instead of appropriate application of nutrient, there was urge of development of Zn and Fe efficient variety (Graham *et al*., 1992) [23].

Conventional breeding approaches

There is diversity in germplasm of several crops with which useful traits such as pest resistance, reduced post–harvest losses and high yielding varieties were developed. Likewise, some donors for efficient uptake from soil and storage in edible parts of crop were recognised. Varieties were developed by conventional breeding by crossing with popular varieties and identified donors under ICAR-AICRP for varietal release. This approach includes identification of major genes or genomic regions or mapping of quantitative trait loci (QTL) for high nutrients through tagging followed by introgression into popular varieties. Since it is genetic in nature. Therefore, farmers need not to require additional expenditure and develop through conventional breeding, regulatory constraints are not applicable for their commercial market.

Genetic engineering

A variety of crops are their where there is not availability of desirable trait gene sequences. In that case, desirable Zn and Fe genes from other organism transfer to the targeted crop or variety for accumulation in targeted tissue of crop. But, achievement in the approval of commercial release of variety is a major concern as it is GMO crop. However, biofortification is an economically sustainable intervention to feed Zn and Fe enriched foods in undernourished population

A number of agricultural research ongoing in achieving nutritional security. Global Organisation like Harvest Plus and CGIAR working extensively in this area. Institutions of ICAR, ICMR, SAU and traditional universities have been developing biofortified variety. Most of the working going on major cereal crops as it is wildly utilized by community. Many crop varieties are witness of this biofortification intervention listed in table 3. At 52nd AMPMIP (Annual Meeting of the Pearl Millet Improvement Project) in 2017, it was announced by Dr C. T. Satyavathi, Coordinator of ICAR-AICRP on pearl millet that pearl millet varieties must contain at least 42 ppm of iron and 32 ppm of zinc.

Table 3: Tabulation of crops, nutritional content, growing area and developing organisation

Crop/Variety	Zn (ppm)	Fe (ppm)	For region	Developed by/ released year
Rice-DRR Dhan 45	22.6 ppm in polished grains	-	for Karnataka, Tamil Nadu, Andhra Pradesh and Telangana	ICAR-Indian Institute of Rice Research, Hyderabad- 2016
Rice-DRR Dhan 49	25.2	-	for Gujarat, Maharashtra and Kerala	By ICAR-Indian Institute of Rice Research, Hyderabad, Telangana.
Rice-Chhattisgarh Zinc Rice-1	22	-	for 'direct seeded rainfed, aerobic and irrigated Ecosystem' of Chhattisgarh plains	IGKV, Raipur- 2015
Rice-IET 24760 (Surbhi)	21	-	For Gujarat and Maharashtra	Nuziveedu seeds limited, Hyderabad 2018
Rice-CR Dhan-311 (Mukul)	20	Protein (10.1%)	For Odisha	National Rice Research Institute, Cuttack- 2016
Wheat-WB 02	42.0	40.0	for Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur division), western Uttar Pradesh (except Jhansi division), Jammu and Kathua district of Jammu and Kashmir, Paonta Valley and Una district of Himachal Pradesh and Tarai region of Uttarakhand.	ICAR-Indian Institute of Wheat and Barley Research, Karnal- 2017
Wheat- HPBW 01	40.6	40.0	for Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur division), western Uttar Pradesh (except Jhansi division), Jammu and Kathua district of Jammu and Kashmir, Paonta Valley and Una district of Himachal Pradesh and Tarai region of Uttarakhand	Punjab Agricultural University, Ludhiana under ICAR-AICRP on Wheat & Barley- 2017
Wheat- Pusa Tejas (HI 8759	protein (12%), and zinc (42.8	42.1	for Madhya Pradesh, Chhattisgarh, Gujarat, Rajasthan and Uttar Pradesh	ICAR- IARI, Regional Station, Indore, Madhya Pradesh- 2017
Wheat - Pusa Ujala (HI 1605	protein (13%and zinc (35 ppm	43	for Maharashtra, Karnataka and Tamil Nadu	ICAR- IARI, Regional Station, Indore, Madhya Pradesh- 2017
Wheat- MACS 4028	High protein (14.7%), and zinc (40.3 ppm	46.1	for Maharashtra and Karnataka	Agharkar Research Institute, Pune, Maharashtra, under ICAR-All India Coordinated Research Project on Wheat and Barley
Pearl millet- HHB 299	41.0	73.0	for Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu	CCS-Haryana Agricultural University, Hisar in collaboration with ICRISAT, Patancheru under ICAR-AICRP on Pearl millet- 2017
Pearl millet- AHB 1200	45-50	73	For Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu.	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (MS) in collaboration with ICRISAT, Patancheru under ICAR-AICRP on Pearl millet- 2017
Pearl millet- ICTP 8203 (Dhanshakti)	40	71.0	Maharashtra, Karnataka, Telangana, Uttar Pradesh, Haryana and Rajasthan.	ICRISAT 2013
Pearl millet- ICMH 1201	40	75	Maharashtra and Rajasthan	AICPMIP 2014
Lentil- Pusa Ageti Masoor	-	65.0	for Uttar Pradesh, Madhya Pradesh and Chhattisgarh	ICAR-Indian Agricultural Research Institute, New Delhi-2017
Pomgranate- Solapur Lal	6.4-6.9	56-61, vitamin C (194-198)	for semi-arid regions	ICAR-National Research on Pomegranate, Pune- 2017

(Yadava *et al*., 2017; Singh, 2017) [24, 25].

Minor millets role in Iron Fortification

Most neglected area in crop production crop during green revolution and present scenario are minor millets which have great potential in accmulation of minerals. In addition, genetic and breeding biofortification give wings to emerge as potential crop. Some of millets genotype/germplasm recognized high iron content (table 4).

Table 4: Potential minor millets germplasm/genotype of Iron

Genotype/ Germplasm	Fe (ppm)
Finger millet GPU-28	69.9
Finger millet- KMR-216 & PR-10-21	More than 90
Finger millet- BR-36 (Chhattisgarh ragi-2)	More than 90
Foxtail millet- SiA 3088 (Surya Nandi)	129
Foxtail millet- SiA 3142 & TNAU-186	More than 140
Little millet- OLM-203	51
Little millet- BL-4, RLM-186, TNAU-63 & JK-8	More than 250

Source: Division of crop science, ICAR, New Delhi (Singh, 2017) [25].

Current scenario of Zn and Fe biofortification Development

Around the world many researches have been conducting for development and identification of potential strain of different crops through different methods of biofortification. Some more Status of Biofortified Crops by transgenic means, conventional breeding or and Agronomic way have given below in table 5.

Table 5: Tabulation of crops, nutrients, research status, and concerned publications on biofortification by transgenic means, conventional breeding and Agronomic means.

Crop	Type of Biofortification	Zn/Fe	Status	Papers
Rice	Transgenic	Iron	Research	Takahashi *et al.* [26]; Lee and An [27]; Zheng *et al.* [28]; Lee *et al.* [29]; Trijatmiko *et al.* [30]; Goto *et al.* [31]; Vasconcelos *et al.* [32]; Lucca *et al.* [33]; Wirth *et al.* [34]; Masuda *et al.* [35]; Masuda *et al.* [36].
	Agronomic			He *et al.* [37]; Yuan *et al.* [38]; Fang *et al.* [39]; Wei *et al.* [40].
	Transgenic	Zinc	Research	Lee and An [41]; Masuda *et al.* [42].
	Agronomic			Wei *et al.* [43]; Boonchuay *et al.* [44]; Jiang *et al.* [45]; Mabesa *et al.* [46]; Shivay *et al.* [47]; Fang *et al.* [39]; Ram *et al.* [48].
Wheat	Transgenic	Iron	Research	Sui *et al.* [49]; Borg *et al.* [50].
	Agronomic			Aciksoz *et al.* [51].
		Zinc		Cakmak *et al.* [52]; Yang *et al.* [53].
Maize			Research	Alvarez and Rico [54]; Lopez-Valdivia *et al.* [55]; Fahad *et al.* [56]; Wang *et al.* [57]; Zhang *et al.* [58].
Barley	Transgenic	Zinc	Research	Ramesh *et al.* [59].
Chickpea	Agronomic			Shivay *et al.* [60].
Pea				Poblaciones and Rengel [61].
Potato				White *et al.* [62].
Lettuce	Transgenic	Iron		Goto *et al.* [63].
Cassava	Transgenic			Sayre *et al.* [64].
	Breeding	Iron	Research	Maziya-Dixon *et al.* [65]; Chavez *et al.* [66].
Potato	Breeding	Fe and Zn	Research	Burgos *et al.* [67]; Brown *et al.* [68].
Beans	Breeding	Fe and Zn	Rwanda: RWR 2245; RWR 2154; MAC 42; MAC 44; CAB 2; RWV 1129; RWV 3006; RWV 3316; RWV 3317; RWV 2887	Asare-Marfo *et al.* [69].
Cowpea	Breeding	Iron	Pant Lobia-1, Pant Lobia-2, Pant Lobia-3, Pant Lobia-4	G.B. Pant Agriculture University, HarvestPlus

Conclusion

Malnutrition is one of the major hurdles in the way of India’s development. Our diet lacks essential nutrients like Zn, Fe, I etc and several vitamins resulting in severe health problems. The remedy of this problem lies in the process of biofortification which seems to be the most cost effective and sustainable way of increasing the availability of essential minerals and vitamins in our diets. Since Iodine requirements can be met through use of iodized salts, our efforts are mainly concentrated towards Zn and Fe biofortification. Biofortification can be achieved mainly by two approaches: Firstly, through agricultural interventions by agronomic intervention and secondly by genetic manipulation or conventional breeding. Various biofortified varieties of rice (Rice-DRR Dhan 45, DRR Dhan 49, Chhattisgarh Zinc Rice-1, IET 24760, CR Dhan-311), wheat (WB 02, HPBW 01, Pusa Tejas, Pusa Ujala, MACS 4028), Pearl millet (HHB 299, AHB 1200, ICTP 8203, ICMH 1201), Lentil (Pusa Ageti Masoor), and Pomegranate (Solapur Lal) has been successfully released in India. Further, biofortification can also increase the potential of several minor millets which were heavily neglected during green revolution. Several biofortified varieties of beans and cowpea have also been released in the world and many more such varieties are soon to be released. Hence, biofortification seems to be the best alternative to combat problem of malnutrition in sustainable manner and to achieve “Kuposhan Mukt Bharat’’ by 2022.

Future

Many researches still in progress for biofortification for different crops. As many cereals has lesser absorption capacity due to higher phytate and phytate-micronutrient ratio. Dephytinization in cereals could be an approach to increase absorption in gastro-intestinal areas (Vashishth *et al.*, 2017) [70]. Many developing countries looking biofortification as boon for poorer society. As many as 1 billion people will be benefited from biofortified foods by 2030, according to Dr. Bouis (Harvest Plus, 2018) [71].

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