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Biofortification in India: Present status and future prospects

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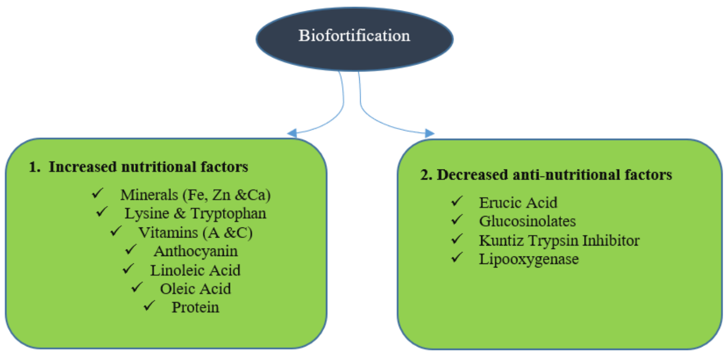
Abstract
Biofortification is the process by which the nutritional quality of food crops is improved through conventional plant breeding, agronomic practices and modern biotechnology. Biofortification of food is possible through two ways. First one, by increasing desirable nutrients viz., provitamin-A, vitamin-C, protein, iron, zinc, calcium, lysine, tryptophan, anthocyanin, oleic acid and linoleic acid in staple food crops and second one by reducing antinutritional factors viz., erucic acid, glucosinolates and trypsin inhibitor. These biofortified cultivars are also high yielding, thus ideal for both 'nutritional and food security'. Indian agricultural institutes has developed and released 71 nutrition rich crop cultivars in important crops like wheat, rice, maize, pearlmillet, fingermillet, groundnut, mustard, lentil, small millet, linseed, soybean, cauliflower, potato, sweet potato, pomegranate and greater yam. The newly developed biofortified varieties besides serving as an important source for livelihood to poor people assume great significance in nutritional security.

Keywords: biofortification, nutritional security, malnutrition, crop varieties, food security

Introduction
Fortification is the practice of intentionally increasing the amount of an essential micronutrient, i.e. vitamins and minerals in daily meals, so as to improve the nutritional quality of the meal and provide a public health benefit with minimal risk to health (Allen *et al*., 2006) [1]. Biofortification is the process by which the nutritional quality of food crops is improved through conventional plant breeding, agronomic practices and modern biotechnology. Biofortification differs from conventional fortification in that biofortification aims to increase beneficial nutrient levels in staple food crops during plant growth rather than through manual means during processing of the crops. Biofortification may therefore present a way to reach poor and malnourished populations where supplementation and conventional fortification activities may be difficult to implement and limited. Nutritious diet is vital for suitable growth and development in humans. It helps in preventing diseases and maintaining the body metabolism for mental and physical well-being. Food provides energy, provitamin-A, vitamin-C, protein, iron, zinc, calcium, lysine, tryptophan, anthocyanin, oleic acid and linoleic acid to meet our daily metabolic requirement. Most of them cannot be synthesized in human body, therefore are to be supplemented through diet. Further, anti-nutritional factors viz., erucic acid, glucosinolates, trypsin inhibitor etc. are present in edible parts of the food brings adverse effects on human health thus reduction in these anti-nutritional factors is also a key objective of biofortification programs.



Consumption of unbalanced foods affects millions of people in India, and leads to poor health and socio-economic conditions. Up to now, the focus of scientist has been on the development of high yielding varieties primarily to feed the ever increasing populations with less focused on quality. Nutritious food is central to nation's growth, development and prosperity. However, malnutrition has emerged as a major health challenge in present situations and is being aptly addressed through Sustainable Development Goals (SDGs) chartered by United Nations. The related top three SDGs are no poverty, zero hunger and good health and well-being (SDGs, 2015) [9]. Various stratigies viz., food fortification, medical supplementation and food diversity are used to alleviate malnutrition.

Why we need biofortification

Global food policy report of International Food Policy Research Institute Washington, DC states that 21.9% of India's population lives in extreme poverty and 15.2% of people are undernourished (GFPR, 2016). The percent of undernourished peoples are high because of unavailability of diversified diet due to poverty. Millions of people cannot afford such diet hence this cannot be the practical solution. The strategy of biofortification of staple food crop varieties with vitamins and minerals is gaining impetus in many developing countries. It has proven a successful strategy in many developed countries because it offers many advantages over food diversification and artificial food fortification. As per the National Family Health Survey, 38.4% of the children (<5 years) are stunted, 21.0% are wasted and 35.7% of the children are under-weight (NFHS, 2015-16). According to Harvestplus-India report, 70% of children (<5 years) are estimated to be iron deficient and 38% of children (<5 years) are estimated to be deficient in zinc (Harvestplus, 2021). Iron deficiency impairs mental development, increases weakness and may increase the risk of women dying in childbirth. Zinc deficiency contributes to stunting and loss of appetite, lowers immunity, and increases the risk of diarrheal disease and respiratory infections.

Advantages of biofortification

i. **Effective outreach (Reaching the malnourished in rural areas)**: The biofortification strategy seeks to put the micronutrient-dense trait in the highest-yielding and most profitable varieties targeted to farmers. Biofortification has advantage over many other fortification processes involved in improving nutritional status of people as this is targeted to population through the staple food. Many artificially fortified and processed foods are beyond the reach of poor people and their introduction to daily diet through different programs is time consuming and labour intensive.

ii. **Cost-effectiveness and low cost:** Biofortified seeds include improvement in the variety of crop by introduction of some specific nutritional superior traits into their seed variety. These varieties are capable of producing nutritionally dense staples and are resistant to many environmental pressures so at the same cost of seed, farmer get nutritionally superior seed for nutritionally rich staple food production.

iii. **Sustainability of biofortification:** Once the crop is introduced with nutritionally superior trait, its seeds and products will contain the same genotype and the cycle will continue without much further investment as compared to other methods of supplementations or artificial fortification.

iv. Change in eating habits and dietary patterns of a population are not essential.

v. A substantial proportion of the recommended dietary allowances (RDA) for different micronutrients can be delivered simultaneously in a continuous manner (Yadav *et al.*, 2020) [12].

vi. Fortified seed does not incur yield penalty.

vii. Offers important indirect benefits like diseases resistance to nutritionally superior plants,

viii. Overcome malnutrition

ix. Increase in nutritional content

x. Improvement of variability in germplasm

xi. Increased bioavailabilty (Kuntiz trypsin inhibitor inhibits bioavailability of trypsin so zero Kuntiz trypsin inhibitor varieties of soybean like NRC 127 are good for health)

xii. Reduced off-flavours (low lipoxygenase good in Soybeans because it responsible for off-flavours)

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 (Yadava *et al.*, 2019) [13]. 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.

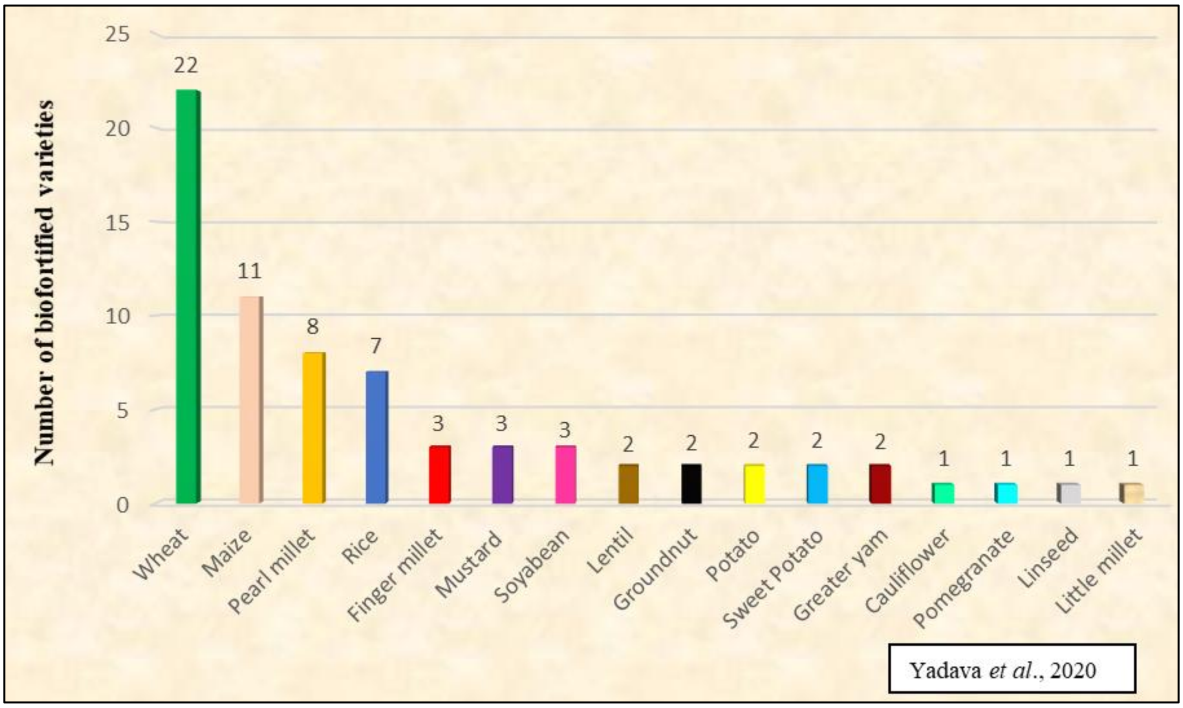


Fig 1: Crop-wise biofortified varieties developed through plant breeding

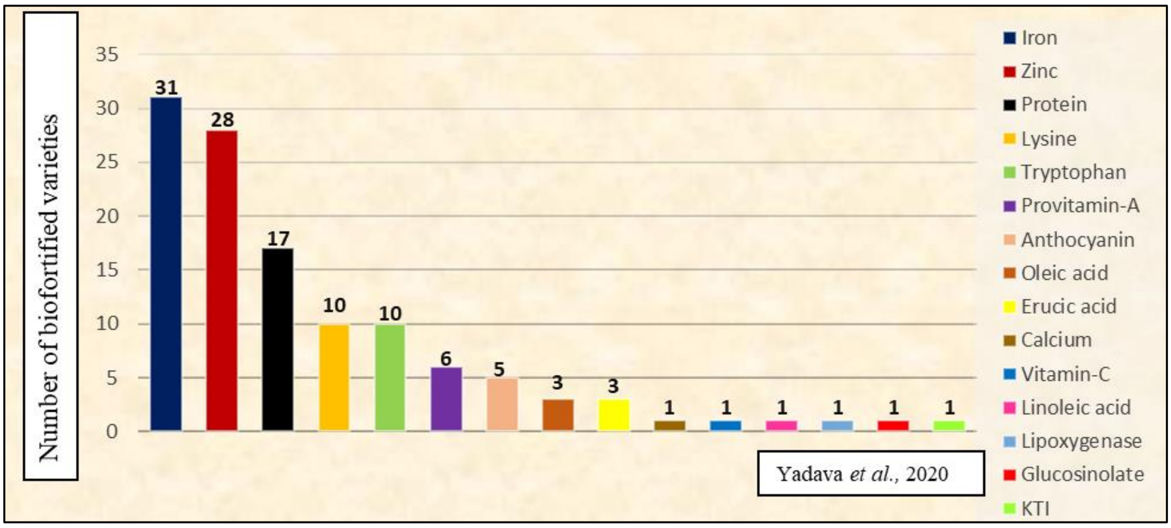


Fig 2: Trait-wise biofortified varieties developed through plant breeding

Table 1: List of released different biofortified crop varieties/hybrids in India

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 compare to 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 in popular cultivars)
13.	Pomegranate	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)

*less than 2% erucic acid in oil desirable for human health
#less than 30 PPM glucosinolates in oil cake desirable for animal health

Approaches of biofortification

There are three main approaches of biofortification. These are as follows-

1. **Agronomic:** Addition of the appropriate nutrient as an inorganic compound as the fertilizer increases the mineral content of the plant as demonstrated successfully in crops like rice, wheat and maize (Bouis *et al*., 2010) [2]. However the strategy is difficult to apply generally because of the additional expenses involved and gain depends on the properties of nutrient and response of the crop.
2. **Conventional breeding**: India is one of the mega centres of agro-biodiversity and limited efforts have been made to evaluate the promising germplasm for enhanced nutrients in several crops. With some identified donors for high nutrients, varieties are being developed through conventional breeding by crossing with popular varieties. Recent approaches for biofortification include identification of genomic regions/candidate genes for high essential nutrients through gene tagging and identification of major genes or quantitative trait loci (QTL) followed by their introgression into popular varieties. (Neeraja *et al*., 2017) [7]. Biofortified crops are developed through conventional breeding have advantage over transgenic approaches because regulatory constraints are not applicable for their release.
3. **Genetic engineering**: In some cases, genetic variability for desirable target traits for biofortification is not available in the germplasm. Hence, genetic engineering is the only viable option. The methodology involves introduction of genes from novel sources for desirable target traits and has advantages of unlimited access to the genes of interest, targeted expression in tissues of interest, rapid and direct application by introduction into popular varieties and stacking of different genes. Several transgenic experiments in many agricultural crops targeted protein and micronutrient accumulation in target tissues (Pandey *et al*., 2015 & Swamy *et al*., 2016) [8, 10].

The popular example is 'Golden Rice' for β-carotene (Tang *et al*., 2009) [11]. However, limited progress for release has been made so far, mainly due to constraints of intellectual property and regulatory issues.

Future biofortification projects of FAO are

- Zinc-biofortification of rice, wheat, maize, beans and sweet potato.
- Iron-biofortification of wheat, rice, pearlmillet, sweet potato and legumes
- Amino acid and protein-biofortification of sorghum and cassava
- Provitamin - A and carotenoid biofortification of maize, cassava and sweet potato.

Conclusion

Globally micronutrients deficiency (essentially vitamins and minerals) causes diseases, particularly in women and children. Thus food fortification is an important and most feasible approach to combat malnutrition particularly in developing countries. Government along with other national organizations like ICAR, DBT, ICMR and international organizations, *viz*. HarvestPlus, IRRI are now converging their research efforts of biofortification for product development, testing and validation. Most important Staple food crops *viz*., Rice, Wheat and maize are getting more attentions as appropriate tools for fortification. The impact and sustainability of biofortification depends on breeding techniques, which enhances nutrient levels without penalty their yield, willingness of farmers for biofortified crops production and their adoption by consumers. With proper planning and implementation, biofortified food crops will help India address the malnutrition problem with minimum investment in research and have a significant impact on the lives and health of millions of needy people of the country.

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