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Biofortification and its Impact on Human Health

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Abstract

India accounts for ~17.7% of the world population and holds 1st position in the world. Despite having huge population pressure, India is now self-sufficient in food production. Human resource is the most important wealth of a country. However, a large number of Indian people are suffering from malnutrition owing to nutritional insufficiency in staple food. Malnutrition and impaired human health are one of the major obstacles for country's development, and monetary loss pertaining to malnutrition is ~ US$12 billion GDP year^{-1}. There are different approaches to increase the quality of food with essential compounds and biofortification is one of the cheapest methods to alleviate this problem. Agronomic biofortification deals with external growth factors while genetic biofortification deals with plant genetic character for higher acquisition and synthesis of essential elements and their remobilization in plant's edible part. In this article, an insight was given on the significance of biofortification in India, different methods of biofortifications and its impact on human health.

Keywords:

Agronomic biofortification, biofortified varieties, soil-plant-human nexus

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1. Introduction

There are four different methods to get nutrient enriched food: (a) dietary diversity, (b) food fortification, (c) supplementation, and (d) biofortification. Among them, Biofortification is an effective process for improving the nutritional quality of foods through conventional plant breeding, agronomic practices, and modern biotechnology. The word "Biofortification" was derived from Greek word "bios"- life, and the Latin word "fortificare"- to make strong. Biofortification is possible in two ways: by increasing the desirable essential elements/ compounds i.e., iron (Fe), zinc (Zn), provitamin-A, protein, lysine, tryptophan, anthocyanin, oleic acid, linoleic acid, etc. and by lowering the detrimental nutritional elements (erucic

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acid, glucosinolates, and trypsin inhibitor) in food grain, without compromising the yield. Biofortification differs from conventional fortification. Biofortification implies the magnification of beneficial nutrient levels in staple food crops during plant growth to get higher essential elements in edible plant parts, whereas, latter indicates the deliberate nutrient supplementation process during the time of food processing to ensure an adequate nutritional quality of food for minimizing the health risk. Considering the wide spread micronutrient deficiency in soil, preponderance of undernutrition in different age group, and socioeconomic condition of the Indian citizen (21.9% of total population belongs to below poverty line), biofortification is the cheapest, sustainable, and most effective way to alleviate the nutritional insecurity in India and in the world as well.

2. Significance of Biofortification in India

2.1. Population pressure and prevalence of malnutrition

➢ Presently, India accounts for ~17.7% of the world population and population pressure is increasing in an alarming rate. With myriads of scientific researches, India has reached at the level of ~332 million tonne food grain production which is now sufficient to feed the huge population. However, foods are not nutritious due to dilution effect (deterioration of nutrient content due to higher yield). Hence, nutritional enrichment in food along with sustainable production system is the need of the hour.

➢ As per the National Family Health Survey Report-5 (2019-21), In India, ~ 0.5% of total death was due to undernutrition in 2016 and an increasing trend of anaemia was observed in children (from ~58.6 to 67%), women (~53.1 to 57%), and in men (~22.7 to 25%).

➢ According to Harvestplus-India report, 70% of children (<5 years), and 38% of children (<5 years) were detected as deficient in Fe and Zn, respectively (Anonymous, 2022).

➢ The Global Hunger Index (GHI), a tool that measures and tracks hunger globally. Where India's rank is 105th with 27.3 score in 2024, it indicates still serious hunger (Table 1) prevails in India.

2.2. Multi-nutrient deficiency in Indian soil

➢ With a single aim of increasing the productivity, farmers are continuously applying N-P-K fertilizers.

Table 1: GHI score and corresponding level of hunger

Severity of hunger	GHI score
Low	≤ 9.9
Moderate	10-19.9
Serious	20-34.9
Alarming	35-49.9
Extremely alarming	≥ 50

As a result, soil health is getting deteriorated, and soil is becoming micronutrient deficient, due to continuous mining by crop. Moreover, in many cases, micronutrient deficiency is not manifested but causes the yield loss (hidden hunger). Hence, to get higher response with primary nutrient, micronutrient is equally important.

➢ Around 49% of Indian soils are deficient in Zn (Figure 1), likewise, 12% in Fe, 33% in B, 5% in Mn, 3% in Cu, and 11% in Mo, and an increasing trend of micronutrient deficiency in Indian soil was observed since 1950 (Figure 2) (Singh, 2008).

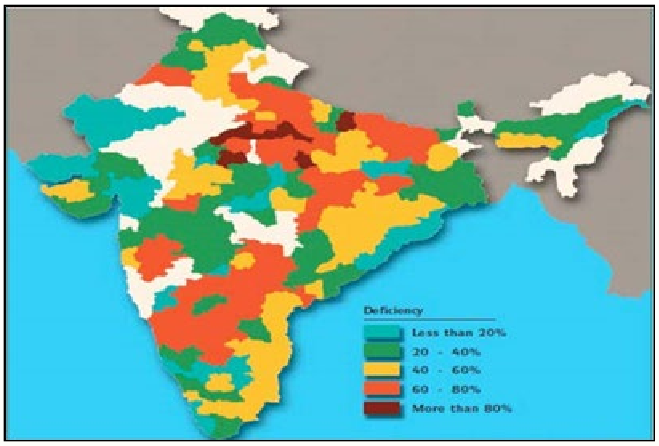

Figure 1: Widespread Zn deficiency in Indian soil (Alloway, 2008)

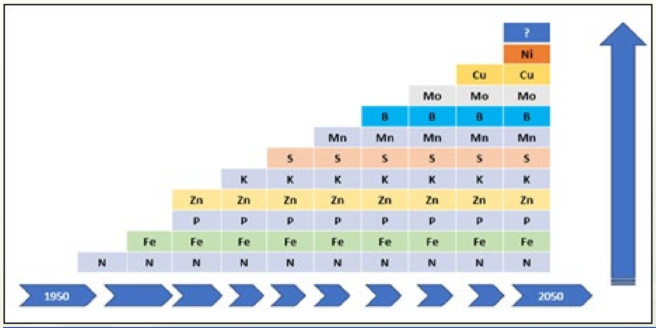

Figure 2: Increasing trend of micronutrient deficiency in Indian soil

2.3. Uncongenial edaphic factors for nutrient availability

➢ **Soil pH:** Soil pH is the most important factors among all edaphic factors which determine the nutrient availability. Soil pH not only affect nutrient availability but also affect the performance of microorganisms. For instance, optimum pH for nitrification is ~8.5 due to the requirement of Ca^{2+} and HPO^{4-} for nitrifying bacteria. In India, ~43 Mha land is having pH <6.5, and there is ~7 Mha salt affected soil. In low pH soil, Ca, Mg, B, Mo and in high pH soil, Fe, Mn, Zn, Cu become less available, and P availability remain less under very high or low pH. Therefore, optimum pH is the prerequisite for higher nutrient availability.

➢ **Calcareous soil:** The abundance of $CaCO_3$ in calcareous soil reduces the availability of Fe and Zn. Zn is precipitated in the form of $ZnCO_3$, and calcium zincate. Moreover, Zn is directly co-precipitated along with calcium carbonate. It has been substantiated that one unit increase in pH, results in 100 times reduction of Zn availability. Owing to higher pH in calcareous soil Fe is also precipitated in the form of $Fe(OH)_3$.

➢ **Water logged soil:** Rice is the most important staple food crop in India, could be grown under water logged condition. Under prolonged waterlogged condition Zn is precipitated as $Zn(OH)_2$ which is not available for plant. Under acidic condition Zn is also precipitated in the form of ZnS. Fe deficiency is predominant in case of aerobic rice due to the preponderance of Fe^{3+} ions which is not/less preferred for uptake. Under water logged condition, though Fe present in the form of Fe^{2+}, in rice root zone it is transformed into Fe^{3+} due to the release of O_2 from root surface. In contrast, during the process of NH^{4+} uptake, rice root releases the H^+ ions which acidify the rhizosphere and help in the process of Zn solubilization. Compendium of the rice root zone chemistry indicates that in aerobic rice Fe, and in lowland rice Zn and Fe are the main essential elements vis-à-vis biofortification.

Hence, in the situation like multi-nutrient deficiency, soil health (physical, chemical, and biological) deterioration, unfavourable climatic and edaphic condition, agronomic biofortification is an indispensable approach to improve the content of essential elements in staple foods.

3. Bioavailability of Micronutrient

Higher nutrient content in food grain is not sufficient to satisfy the goal of biofortification, until it is utilized by human body. There are some compounds in food grain which hinder the bioavailability of micronutrient. For example, phytate, tannins, and some heavy metals (Cd, Hg, Pb) reduce the bioavailability of Zn and Fe. Ideal Zn : phytate is ~15:1 for higher absorption of Zn in human body. Phytate is not a digestible compound in human body and Zn is precipitated with phytate and consequently, Zn absorption is reduced. Amongst all cereals, rice is the best crop to target for agronomic biofortification as the general phytate: Zn molar ratio is only ~5 for rice. However, in maize and sorghum flour the Zn : phytate ratios are 36 and 32, respectively.

Therefore, to reduce antinutritional factors and increase the plant inherent capacity to augment micronutrient acquisition in edible plant parts, and to harness the benefits of agronomic biofortification, genetic biofortification is a potent and sustainable approach.

4. Essential Micronutrients for Plant and Human Health *Vis-à-Vis* Biofortification

Out of the essential nutrients for plants, Fe, Zn, Mn, Cu, B and Mo are also essential nutrients for animals and human beings. It was estimated that about 50% of cereals cultivated soils are Zn deficient and most of the calcareous soils are Fe and Zn deficient. Among the major illness and health related concerns for human beings, Zn and Fe deficiencies affect the large section of population, aggravate the need of biofortification for Zn and Fe. However, Vit-A, Se are also essential for some specific group of people. Therefore, in general, biofortification should be based on nutritional demand of the people and crop specific.

5. Ways and Means of Biofortification

For biofortification, genetic and agronomic approaches (Figure 3) should be followed in tandem. With single

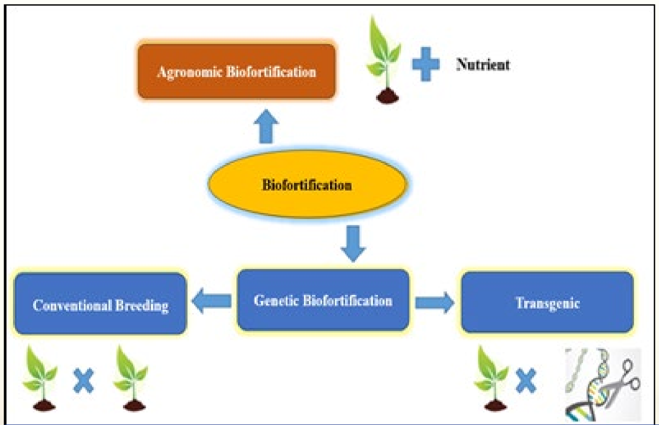

Figure 3: Different approaches of biofortification

approach, the ultimate target shall remain elusive. Different ways and means of biofortification have been briefly explained with following subheadings.

5.1. Agronomic biofortification

There are many methods of agronomic biofortification, some of the important and promising methods have been highlighted below.

5.1.1. Ferti-fortification

External source of nutrient is applied for increasing the availability of targeted nutrient with an aim to augment the higher acquisition of that particular nutrient in grain. Application of nutrient/fertilizer could be done by many ways viz., soil application, foliar feeding, nutri-priming, seed coating, root dipping, fertigation etc.

5.1.1.1. Soil application and foliar feeding

Application of micronutrient containing fertilizer such as $FeSO_4$. $7H_2O$ (19% Fe), $Fe_2(SO_4)_3$. $4H_2O$ (23% Fe), Fe-EDDHA/ Fe-EDDA (5-14% Fe), $ZnSO_4$. H_2O (35% Zn), $Na_2ZnEDTA$ (14% Zn) in soil, can improve the micronutrient availability in nutrient deficient (eg., soil Zn content <0.6 ppm) and high pH (>6.5) soil. 5 kg ha^{-1} Fe-EDDHA (6% Fe), and 25 kg ha^{-1} $ZnSO_4$ is very effective in calcareous soil for improving Fe and Zn availability. Supply of N in wheat through 5% S-coated urea (130 kg N ha^{-1}) in neutral pH (7.3) soil was very effective to get higher micro nutrient content (Fe- 181 ppm, Zn- 44.5 ppm, Mn- 46.8 ppm, Cu- 7.7 ppm) in grain compared to conventional prilled urea (Shivay et al., 2016). Application of Nano-ZnO coated urea and $ZnSO_4$ coated urea are also very effective to get higher productivity and Zn enrichment in grain. In an experiment, 2 times higher recommended dose of N-P-K (120-60-40 kg ha^{-1}) along with 3 times $FeSO_4$. $7H_2O$ foliar spray (3%) resulted in significantly higher Fe content (53.52 ppm) in wheat grain compared to 100% recommended dose of fertilizer (RDF). However, highest Zn content (32.63 ppm) in wheat grain was recorded with 100% RDF+3 times 3% Fe foliar spray (Rakshit et al., 2016). It implied that N - Fe - Zn are synergistically interrelated. In Zn deficient soil, soil application of 25 kg $ZnSO_4$. $7H_2O$ ha^{-1} + 0.2% $ZnSO_4$. $7H_2O$ foliar spray can improve cereal grain yield as well as Zn content. Moreover, Application of micronutrient through fertigation can improve nutrient availability, uptake and recovery owing to the slow and sustained release of nutrient at root zone.

5.1.1.2. Nano technology

Nano fertilizer is a promising tool for increasing nutrient recovery efficiency to a greater extent for its smaller size and slow-release property. Foliar spray of nano chelated iron fertilizer (2.5 g l^{-1}) resulted in 27% higher grain yield and 13% higher protein content in rice grain (Fakharzadeh et al., 2020). Foliar application of ZnO-NPs @ 80 ppm showed the best result in plat height and seed Zn content in wheat. In most of the cases, the result of foliar application was more effective when nano fertilizer was sprayed just before flowering stage.

5.1.1.3. Nutri-priming and seed coating

Soaking of seed in nutrient solution is called nutri-priming. However, its implication in biofortification is not significant compare to other means. Seed soaking with 0.5 M Zn solution irrespective of some microbial treatment was significantly inferior vis-à-vis wheat yield and grain nutrient content. However, seed coating with Zn @ 2500 mg kg^{-1}+Zn foliar spray @ 1050 ppm (2 times) resulted in significant Zn content (46.7 ppm -grain) and uptake (169.1 g ha^{-1} -grain) in transplanted and direct seeded rice (Karmakar et al., 2024).

5.1.2. Green technology

Endophytic microbes, plant growth promoting (PGP) rhizobacteria and nutrient solubilizing bacteria can be utilized in the process of biofortification, this approach is often called as green technology. For instance, endophytic fungus *Piriformaspora indica* can improve plant growth, biomass, and micronutrients uptake. *Bacillus subtilis* (DS-178) and *Arthrobacter sp.* (DS-179) could increase the Zn content by an average of 75% over the control in Zn-deficient soils. Similar results were also found with *Arthrobacter sulfonivorans* (DS-68) and *Enterococcus hirae* (DS-163), with respect to Fe content in wheat grain (Singh et al., 2018). Utilization of PGP rhizobacterium *Pseudomonas fluorescens* was found to be effective for Zn biofortification in wheat grains.

Mechanism of microorganisms for improving the availability of micronutrient:

- Production of siderophores and other chelating substances
- Organic acid secretion and proton extrusion
- Modification in root morphology and anatomy
- Secretion of phenolics
- Secretion of phytohormones

5.1.3. Tillage

Evidence for conventional tillage and hinderance in nutrient uptake is hardly available. However, zero tillage over the year may cause nutrient and carbon stratification in 0-5cm soil layer, as a result, higher availability of primary nutrient may negatively interfere with micronutrient. One pertinent example is P x Zn interaction. Hence, under long term conservation agriculture, inversion of the surface soil is suggested through strategic tillage to reduce the compaction and nutrient stratification related problem.

5.1.4. Water management

Water acts a medium for nutrient uptake and translocation. Precise water management is very important to maintain the nutrient availability in soil. In case of rice, prolonged water stagnation reduce Zn and Fe availability as these nutrients are precipitated as Zn and Fe hydroxides, and in aerobic rice, Fe deficiency is predominant. To overcome this problem, alternate wetting and drying is a promising solution with less water footprint. In calcareous soil, excess water and anaerobic condition can increase the Zn availability.

5.1.5. Diversified cropping system, green manuring, and other practices

Diversified cropping system is one the principles of sustainable and climate resilient food production system. Different root morphology/character of a diversified cropping system can potentially aggravate the nutrient cycling process across the soil profile. Introduction of legume not only improves the soil health but also improves the micronutrient availability in soil owing to the more acidic root exudation.

Addition of organic matter with green manuring has also been proven as a sustainable approach for biofortification in cereals along with other ecosystem services (Pooniya et al., 2012). Mulching in winter season can maintain soil optimum temperature which facilitates macro/micro nutrient availability and microbial activity in soil.

5.2. Genetic biofortification

There are mainly two methods of genetic biofortification viz., conventional breeding and transgenic crop. Golden rice is the classical example of a transgenic rice, enriched with beta-carotene due to the incorporation of Daffodil's and soil bacterial gene for the synthesis of phytoene synthase, phytoene desaturase, carotene desaturase, and lycopene-beta-cyclase enzyme. Important biofortified varieties of some important crops developed through conventional breeding, have been tabulated in Table 2 with their desirable potential.

6. Impact on Human Health

Multifarious benefits of biofortified food on human health have been enlisted in Table 3.

Table 2: Recently developed biofortified varieties of some important crops

Crop	Normal level of protein/ micronutrient	Biofortified traits	Biofortified varieties	Characteristics
Rice	Protein ~7%, Zn ~16 ppm	High Protein	CR Dhan -310	~10.3% protein
		High Zn content	DRR Dhan - 45, DRR Dhan – 48, DRR Dhan – 49, Zinco Rice MS and CR Dhan – 315	~24 ppm Zn
Wheat	Protein ~8-10%, Zn ~26ppm, Fe ~32ppm	High Fe content	HD – 3249 and DBW -187	~42 ppm Fe
		High Zn content	PBW – 771, PBW – 757 and HD – 3171	~42 ppm Zn
		High protein and Fe	HD – 3298, HI- 8805 (Durum), DDW – 47 (Durum)	~12.8 % protein and ~40 ppm Fe
Maize	Lysine ~0.15-0.25%, Tryptophan ~0.03-0.04%	High lysine and tryptophan	Vivek QPM – 9, Pusa HM – 4 Improved	~4.19 % lysine and ~0.83% tryptophan
Pearl millet	Zn ~32ppm, Fe ~42ppm	High Fe and Zn	HHB - 299, RHB - 234, RHB -233	~83 ppm Fe and ~45 ppm Zn
Lentil	Fe ~47 ppm, Zn ~22 ppm	High Fe and Zn	IPL – 220	~73 ppm Fe and ~51 ppm Zn

Table 3: Impact of biofortified nutritious food on human health

Essential elements for biofortification	Impact of nutritious food on human health
Zn	➢ DNA synthesis without defect ➢ Proper cell growth and protein synthesis ➢ Quick wound healing ➢ Strong immune system ➢ Support during growth phases ➢ Proper nerve function related to taste and smell
Fe	➢ Adequate and proper oxygen transport ➢ Prevention of fatigue ➢ Proper brain development and growth ➢ Proper cell division and hormone production
Protein	➢ Structural integrity: Adequate protein intake is vital for the formation and maintenance of bones, muscles, cartilage, and skin ➢ Efficient tissue repair and recovery ➢ Efficient oxygen transport: Proper protein levels are essential for the production of hemoglobin, a protein in red blood cells that efficiently carries oxygen throughout the body ➢ Hormonal balance: Adequate protein intake is essential for regulating hormones, particularly during critical growth and developmental stages such as puberty, where it supports the transformation and function of cells
Vit-A	➢ Vision support: Consuming vitamin A-rich foods is essential for maintaining normal vision, particularly in low-light conditions, and preventing vision-related issues ➢ Efficient immune system ➢ Proper functions of reproductive organs ➢ Healthy growth and development

Source: https://www.health.harvard.edu/topics/nutrition

7. Conclusion

Agronomic and genetic biofortification are essential and complementary approaches for ensuring food and nutritional security. However, FAO presently proposed that without nutritional security food security cannot be achieved. Both high yield and adequate nutrient content are crucial to meet the needs of a growing population. However, high-yielding biofortified varieties and agronomic techniques are underutilized by farmers. Hence, extension wing should be active to popularize the concept of biofortification to harness the real benefit.

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