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Bio-fortification through Major and Minor nutrients: A review

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Abstract

Biofortification is the process of enhancing a food crop's micronutrient content through various methods like selective breeding, genetic manipulation, or the application of enriched fertilizer. Iron, zinc, and vitamin A deficits are the focus of biofortification research. Biofortification can be accomplished by traditional plant breeding or transgenic techniques. In India, biofortification is the sole way to make biofortified crops. New varieties are created by crossing promising lines and choosing those with desirable traits. It involves integrating DNA into an organism's genome to introduce new attributes such as disease resistance or micronutrient. Biofortification is more cost-effective than supplementation or fortification in lowering the burden of micronutrient deficiency, especially in Asia. Traditional breeding techniques are the most successful and long-term approach for biofortifying crops, but they are time-consuming and require a lot of genetic variety in the plant gene pool.

Keywords: Biofortification, micronutrients, nutrient, zinc, deficiency, iron

Introduction

It is the process of enhancing a food crop's micronutrient content through various methods like selective breeding, genetic manipulation, or the application of enriched fertilizer (Bouis *et al.*, 2011) [7]. Biofortification improves the nutritional value of crops during the plant growth stage by incorporating nutritional micronutrient content in the crop. Iron, zinc, and vitamin A deficits are the focus of biofortification research. These are the micronutrients that affect the greatest number of individuals around the world. Because grains are inherently low in important micronutrients, there is widespread worry about the ability to generate nutritionally rich food. Furthermore, due to the rapid growth of the human population and industrialisation, this scenario may be exacerbated by the cultivation of cereals in areas with limited mineral availability (White and Broadley, 2009) [72]. As a result, hunger and bad health harm these individuals, who may experience blindness or stunting, as well as fatality. Medical supplements and fortification have been pursued to address this "hidden hunger" (Underwood, 2000) [75]. Micronutrient intakes among the poor can be raised by increasing the micronutrient content of energy-rich crops, resulting in a decrease in the prevalence of micronutrient deficiencies.

It varies from traditional fortification in that it focuses on making plant foods more nutritious while they are still growing, rather than adding nutrients after they have been processed. Vitamins and minerals have usually been distributed to the general public through nutrient supplementation programmes, but this falls short of the international health organisations' aims because supplementation programmes rely on external financing that is not guaranteed from year to year. Other constraints include impoverished people's purchasing power, access to markets and health-care systems, and a lack of knowledge about the long-term health benefits of these mineral supplements (Choudhary and Saran, 2020) [14].

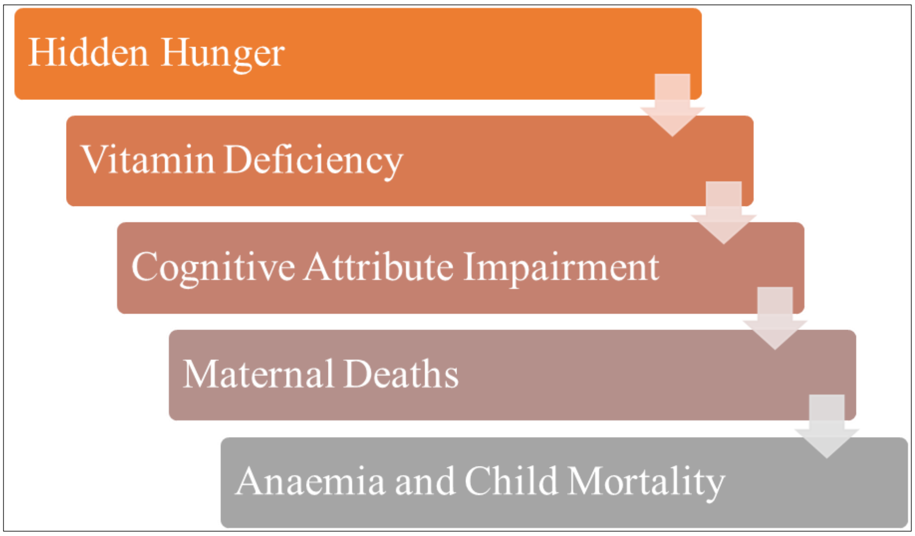
Biofortification can be accomplished by traditional plant breeding, which involves crossing parent lines with high vitamin or mineral levels over multiple generations to generate plants with the necessary nutritional and agronomic characteristics. However, once a transgenic line has been developed, several years of traditional breeding are required to ensure that the transgenes are inherited in a stable manner and that the transgenic line is incorporated into farmer-favoured cultivars. While transgenic breeding can occasionally provide micronutrient advantages not accessible to conventional breeders, many nations lack the legal structures necessary to allow the distribution and marketing of these cultivars (Saltzman *et al.*, 2013) [61].

Biofortification can increase the nutritional value of the staple foods that the poor already consume through plant breeding, offering a relatively cheap, efficient, sustainable, long-term method of giving the poor with more micronutrients (Bouis *et al*., 2011) [7].

The ultimate goal of the biofortification strategy is to reduce mortality and morbidity rates associated with micronutrient malnutrition, as well as to improve food security, productivity, and quality of life for poor populations in developing countries, by breeding staple crops that provide improved levels of bioavailable micronutrients at low cost and in a long-term sustainable manner (Sharma *et al.*, 2016) [63].

Importance and need

Biofortified crops may be able to provide iron, zinc, and vitamin A to the people who do not have access to the good food. The most obvious benefit of biofortification is that it is appropriate for the poor, who typically consume staples that are not processed and advertised for sale commercially but rather rely on homegrown foods. Hence, biofortification has the potential to reduce the incidence of micronutrient deficiencies and the number of people who need interventions, such as fortification and supplementation, to enhance the nutritional value of meals. The new variety must have a high yield and be disease and pest resistant, in other words, it must be economical. Furthermore, the micronutrient level must have the ability to considerably improve human health and ensure proper mineral bioavailability. The amount of Fe, Zn, and Vitamin A necessary for biofortified crops is the breeding target, which is a mix of baseline and increment that is set to satisfy the specific dietary requirements of women and children, based on existing consumption trends (Choudhary and Saran, 2020) [14] Two possible biotechnological uses that arise are the biofortification of mineral micronutrients in food crops for human nutrition and phytoremediation of metal/metalloid polluted soils. from mineral uptake, transport, and storage research both of these aims are significantly different in plants' metabolism (Zhao & McGrath, 2009) [75].



Challenges of biofortification

Biofortification is more cost-effective than supplementation or fortification in lowering the burden of micronutrient deficiency, according to a recent projection, especially in Asia (Meenakshi *et al*., 2010) [33]. The agronomic approach using micronutrient fortified fertilisers is the simplest method for developing biofortified crop cultivars, but it is highly variable due to changing mineral transportation and accretion behaviour among different crop plants, as well as variable soil compositions at different geographical locations. Furthermore, it is a costly and time-consuming strategy, as it necessitates constant micronutrient inputs for the plant and soil. Furthermore, because micronutrients are often stored in non-edible parts of plants, such as leaves, rather than the seeds or fruit, this practise is effective in a limited number of plant species and minerals. Furthermore, the most significant disadvantage of this strategy is the negative environmental consequences of over-application of fertilisers, which results in their accumulating in soil and water reserves.

Traditional breeding techniques are the most successful and long-term approach for biofortifying crops, but they are time-consuming and require a lot of genetic variety in the plant gene pool to increase micronutrient characteristics. As a result, conventional breeding is ineffective for many qualities, such as improving oil quality or increasing Se, due to restricted diversity, low heritability, and linkage drag. Because multiple genes are involved in controlling mineral elements that are changeable in diverse genetic and environmental backgrounds, estimating and introgression of micronutrient characteristics is a difficult task.

Effect of Biofortification on yield

Keram *et al.* (2012) [78], conducted an experiment and observed that applying the required NPK + Zn @ 20kg/ha by wheat as opposed to NPK alone significantly boosted yield, harvest index, nutrient (N, K, and Zn) uptake and quality. In general, with the exception of total P absorption, yield, harvest index, total nutrient uptake, and quality all rose up to the highest level of Zn. The application of 20 kg Zn/ha with recommended NPK as compared to control and other treatments produced the highest yield (grain 4.66 t/ha and straw 5.44 t/ha), harvest index (46.07), total nutrient uptake (N 123.19 kg/ha, K 90.86 kg/ha, and Zn 327.74 g/ha), total carbohydrate (70.37%), and gluten (12.37%) content.

Chaube *et al.* (2002) [11], observed that soil application of zinc sulphate @ 25 kg/ha resulted in considerably greater groundnut seed production (2512kg/h*a), haulm yield (5218kg/h*a), and pod yield (3888kg/h*a) when compared to control.

Shanker *et al.* (2003), also observed that the optimal soil application combination for increasing groundnut yield was ZnSO4 at a rate of 20 kg/ha combined with 0.05 kg/ha of borax.

In an experiment conducted by Reddi Ramu and Reddy (2007) [42] found that Foliar application of Zn and Fe resulted in higher plant height, LAI, dry matter production and yield attributes of maize *viz*., number of seeds and grain weight cob¹, 100- seed weight and seed yield, which were comparable with the soil application of Zn and Fe. Similar trend was observed with respect to protein and tryptophan content in grain and crude protein content in stover.

Sabra *et al.*, (2019) [60] studied on response of growth characters, yield and yield attributes of groundnut cultivars to some micronutrients foliar spraying application at the Production and Research Station, National Research Centre, El-Nubaria Province, El-Beheira Governorate, Egypt during 2015-16 and found micronutrient Zn, Mn, B foliar spray treatment recorded highest value of height (76.23 cm), fresh weight/plant (259.22 g) and dry weight/plant (129.00 g) and pods plant^{-1} and seeds plant^{-1} was 39.86 70.07 respectively which is on par with application of Zn+B (Pods plant^{-1} 36.83 Seeds plant^{-1}).

Arunachalam *et al.*, (2013) [3] conducted an experiment on response of groundnut genotypes to soil fertilization of micronutrients in alfisol conditions groundnut micronutrient treatment at Dryland Agricultural Research Station (DARS), Chettinad during 2011 and evaluated the improved quality of the kernel by increasing zinc content and also contributed to a significant increase in pod production of cultivar TMV 7 from 19.2 to 21.4 g, TMV (Gn) 13 from 18.4 to 22.5 g and VRI (Gn) 6 from 35.7 to 38.6 g. The overall increase in pod yield per plant was 12.6 percent.

Chaudhary *et al.*, (2017) [28] studied Zn-biofortification in groundnut through various Zn-sources and found that, crop showed good response to all the applied sources of Zn but maximum increase in pod yield was due to zinc sulphate and zinc acetate, on average Zn application raised the yield by 18% in groundnut. Reddy *et al.*, also at Naini Agriculture Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India during kharif, 2018- 19 and found that maximum number of pods/plant (23.50 pods/plant), Kernels/pod (2.0 Kernels/pod), pod yield (1.95 t ha-^{1}) and kernel yield (1.38 t ha-^{1}) was recorded in (SSP + Zinc at 25 kg ha-^{1} in combination with 0.25% as foliar application) at 90 DAS

A field experiment was carried out by Dutta and Patra (2005) at Nadia, West Bengal, and it was discovered that soil absorption of 30 kg S/ha generated considerably better groundnut pod yields than 15 and kg/ha and control other levels of S. Gypsum or SSP was the best source of S in terms of production, yield characteristics, and groundnut oil content, followed by elemental S and pyrites. As comparison to the control.

Wadile *et al.* (2005) [79] found that applying 15 kg/ha of sulphur by a single superphosphate resulted in a significantly greater sesame seed output (645 kg ha^{-1}). Saren *et al.* (2004) [49] conducted a field experiment in West Bengal on sandy loam soils and reported that the number of branches and capsules/plant, seeds/capsule, and seed and stalk yield of sesame increased significantly with increasing levels of sulphur from 0 to 45 kg/ha, though it was found to be at parity with 30 kg S/ha in sesame.

In a field study on calcareous soil, Prasad *et al.* (2010) [41] investigated the long-term effects of crop residues and zinc fertiliser on crop yield. They found that the incorporation of crop residues (at a rate of 50%) and a starter dose of 5–10 kg Zn ha^{-1} could sustain crop productivity and preserve soil health.

Pable *et al.* (2010) [41], studied the application of 30 kg S ha^{-1}+2.5 kg Zn ha^{-1}+ RDF resulted in the maximum increase in grain and straw production of 17.55 kg ha' and 31.14 kg ha, respectively, for soybeans grown in Vertisols.

Srikanth *et al.* (2012) [71], in an experiment found that the treatment of 0, 10, 15, and 20 kg of zinc sulphate resulted in seed yields of pigeon pea of 1048, 1171, 1296, and 1324 kg, respectively. The seed weight per plant was greatly influenced by the accumulation of dry matter in pods, and the increase in yield was achieved through improvement in yield-attributing characters like seed weight per plant and 100-seed weight, which were significantly higher with the application of zinc sulphate @ 15 and 20 kg ha over zinc sulphate @ 10 kg ha and no zinc sulphate, respectively.

According to Shaheen *et al.* (2007) [67] the number of tillers per hill (11.77), plant height (62.99 cm), panicle length (9.41 cm), and weight of 1,000 grains (32.37 g) all increased significantly, However, statistically speaking, the plant height figures were equal. When zinc 10kg/ha was applied, grain and straw yields were 8.62 g and 14.84 g per pot, respectively, as opposed to grain and straw yields of 7.27 g and 12.98 g per pot, respectively, with no zinc treatments (ZnO).

Effect of biofortification on quality

According to Mirvat *et al.* (2006) [34], zinc foliar spraying had a substantial impact on chemical constituents such as protein, NPK%, and oil content. Oil content (44.6), protein (25.1), nitrogen (4.1%), phosphorus (0.93%), and potassium (0.76%) were all noticeably higher when zinc concentration was increased from 0.50 to 1.00 g/litre of water.

Singh (1999) [56] reported that the soil and seed application of $ZnCl_2$ and $ZnSO_4$ exhibited a positive response with good germination and enhanced pod yield, pod quantity, and oil content based on the pot and field studies carried out on a medium black calcareous soil in Junagadh (India). When used as seed dressing, both fertilisers, however, were harmful to groundnut seedlings. In a different experiment, adding Zn by drip irrigation raised the amount of chlorophyll, the quantity of pods, and the yield. Also, it kept the soil loose for peg penetration and pod development and improved fertiliser use efficiency. The main benefits of applying Zn using drip irrigation were accurate application at the right times with the necessary concentration, uniform distribution, fewer crop and soil damage, and eventually a greater yield (2523 kg/ha).

Chaudhari *et al.*, (2021) [13] conducted research on effect of Fe and Zn enriched organics on yield, quality and nutrient uptake by summer groundnut at C. P. College of Agriculture, SDAU, Sardarkrushinagar during summer season of 2017 and reported that application of iron and zinc in the form of enhanced FYM or vermicompost increased crop output. Summer groundnut crop yields were highest with application of RDF + 0.2 t Vermicompost ha^{-1} enriched with 1.5 kg Fe ha^{-1} with filled pod per plant was 24.67 and yield of 2523 kg/ha which was on par with RDF + 0.2 t Vermicompost ha^{-1} enriched with 0.75 kg Zn ha^{-1} and RDF + 0.5 t FYM ha^{-1} enriched with 1.5 kg Fe ha^{-1}.

Sumit Sow and Shivani Ranjan (2021) [53] studied Zinc Biofortification in Groundnut and they concluded that when zinc-enriched fertiliser is applied to the soil, the groundnut crop absorbs more zinc and the bioavailable zinc concentration in the edible section of the plant increases.

Mahgno *et al*. (1999) studied the effect of rate of phosphorus and sulphur application on N and P amount in stover and grain of groundnut and found that the amount of phosphorus in grain increased with the application of 20 kg P + 4 kg S, but the amount in stover increased significantly with the application of 40 kg P + 8 kg S ha^{-1} (6.73) kg ha^{-1}.. The highest nitrogen content was found in grain (35.8 kg/ha), whereas the highest nitrogen content in stover (154.6 kg ha^{-1}) was found when 40 KqP + 8 kg S ha^{-1}was applied.

Aulakh *et al*. (1980) [2] Based on the findings of three years of mustard field trials, indicated that maximum oil yields were attained at high N (75 kg ha^{-1}) and S (60 kg ha^{-1}) rates, indicating considerable S and N interaction.

Roy *et al*. (2014) [48] conducted an experiment on the effect of zinc application techniques on green gram grain zinc fortification. According to the findings, soil application and foliar application produced the maximum Zn content (45.7 mg kg1) in seeds. To increase seed Zn concentration, foliar treatment was shown to be superior (1.8-fold in seed) to soil application. This finding may be related to how easily Zn may pass through leaves via transportation or stomatal channel.

Zeidan *et al*. (2010) [77] found that plants treated foliar application with 0.5 percent ZnSO4 along with NPK (80: 50: 75 kg fed^{-1}) produced significantly higher plant height, fresh and dry weight, number of leaves, 100 grain weight, number of tillers, number of spikes m^{-2} (362) grain (3416 kg fed^{-1}), and straw yield (4171kgfed^{-1}) than plants grown in Zn-free environments.

According to Shaban *et al*. (2012), applying zinc at a rate of 10 kg per hectare had a stronger impact on grain protein production than the control. He examined the impacts of zinc (0, 15, 25, 35, 55, and 65 kg ha1) in chickpea, the application of zinc had no significant impact on the protein content of grain storage, but protein yield was considerably greater at 55 kg ha^{-1} zinc than the control. Choudhary *et al*. (2017) [15], compared to the control treatment and zinc 2.5 kg ha^{-1}, the soil application of zinc @ 5 kg ha^{-1} in chickpea substantially increased the grain protein content, protein yield, total absorption of N & P, and production efficiency. However, protein content and total P absorption in chickpea were statistically comparable for zinc at 5 kg ha^{-1} and 2.5 kg ha^{-1}.

Kuldeep *et al*. (2017) [28] studied the effects of fertilization in chickpea with zinc (zinc @ 0, 1.25, 2.5, and 5 kg ha^{-1}). Compared to the control, protein content considerably increased after zinc treatment at 5 kg ha^{-1}. However, it continued to be equal to zinc at 2.5kg ha^{-1}.

In a pot experiment on cowpea, Salih (2013) [50] applied 0, 1, and 2 mg kg^{-1} of zinc to the crop 15 DAS before repeating the procedure every 15 days. The content of nutrients and grain protein increased significantly above the control treatment after foliar spraying with zinc at a rate of 2 mg kg^{-1}.

Effect of Biofortification on Economics

Anthony *et al*. (2015) [6] found that significantly higher net realization, system profitability in returns of the net realisation and employment generation was obtained in sesame + groundnut - castor (108864/ha, 298.3/ha/day and 181 man-days/ha), sesame + green gram-castor systems (108390 ha, 297/ha/day and 178 man-days) and sesame-castor systems (100260 ha. 274.7/ha/day and 189 man-days), respectively. The most profitable system was sesame groundnut-castor, followed by sesame + greengram-castor and sesame-castor, respectively.

According to Yadav *et al*. (2015) [75], there were differences in groundnut cultivation costs, net returns, and B:C ratios depending on the P sources and rates of application. SSP-treated plots had the lowest observed cost of cultivation. Yet, under the (GPG) Godawari phosgold treated groundnut plots, the net returns and B:C ratio were higher. Although the largest net returns (65.45 x 103/ha) and B:C ratios (2.45) were seen with 27 kg P/ha, the cost of cultivation, net return, and B:C ratio all demonstrated an increasing trend with the rate of application.

Patel *et al*. (2007) [39] stated that the maximum B:C ratio (3.79) was obtained when groundnut was manured by FYM and ZnSO, and FeSO @ 25 kg/ha. This was based on an experiment undertaken to explore the effect of sulphur and micronutrient with and without FYM on groundnut and their residual influence on succeeding wheat

Abdel-Galil *et al*. (2015) [4], compared to the conventional cropping system, the intensive cropping system boosted total and net returns by 65.34 and 121.34%, respectively. From $ 1530.9 (conventional cropping system using peanut ev. Giza 4) to $ 4134.1 (intensive cropping system using peanut cv. Ismailia 1) per ha, net return varied between treatments. When compared to a conventional cropping system using the peanut cv. Giza 4, an intensive cropping system employing the peanut cv. Ismailia 1 enhanced net returns by 170%.

Pervaize *et al*. (2003) [80] demonstrated considerably greater net returns (5,755 ha1) and value cost ratio (8.19) in wheat with soil treatment of Fe @ 20 kg ha^{-1}.

According to Singh *et al*. (2013) [57], applying 22.5 kg of zinc per hectare resulted in noticeably greater flag leaf (24.40), yield (44.20 q ha^{-1}), zinc content, and zinc absorption. Zn fertilisation might be raised up to 22.50 kg ZnSO, ha for maximum profit with a benefit above control of around 11,620, according to the higher benefit:cost ratio of 2.91.

According to Rajput *et al*. (1995) [47], foliar treatment of ZnSO4 @ 5kgha^{-1} produced the best net returns, 6.111ha^{-1}, above basal application of ZnSO4 @ 10 kg, while the lowest net returns, 5.684ha^{-1}, were seen with control, totalling 4,249 ha.

According to Khan *et al*. (2010) [29], applying micronutrients had no impact on the quantity of tillers, fruitful tillers, or spike length. Maximum yield per hectare (3670 kg). When Shelter was used at the tillering, jointing, booting, and earing stages, total benefits of 88,080 and net economic returns of 58,384 were noted, with a B.C ratio of 2.97.

Abbas *et al*. (2012) [5] reported that all growth and yield parameters significantly increased when recommended NPK (150.100.60) was applied with soil applications of Fe at 0, 4, 8, and 12 kg ha' during the preparation of the seed bed The application of Fe at 12 kg ha' with recommended NPK produced the highest net return of 548.08 USS ha and the VCR ratio 1.61 US$ ha' with an increase in income over the control 117.93 US$ ha.

According to Shivay *et al*. (2014), applying zinc to chickpea at a rate of 2.5 kg per hectare significantly increased gross and net returns compared to the control treatment. The best net yields were obtained from applying zinc at a rate of 7.5 kg per hectare. In comparison to the control treatment, the soil

applications of zinc at 5.0 kg ha^{-1} in rain-fed chickpea.
According to Anitha *et al*. (2005) [1], foliar spraying cowpea plants with ZnSO4 @ 0.5% at 25 or 45 days after planting increased net returns and the benefit-cost ratio compared to the control treatment. 76 farmer fields were examined in field research.
Dayanand *et al*. (2013) [17] found that applying ZnSO, @ 0.2% as a foliar spray to chickpea throughout the branching and pod-formation phases resulted in greater net returns and a lower benefit-cost ratio than the control treatment.

Table 1: Biofortified Crops with their Nutrients

S.no.	Crop Name	Nutrient	Centre	Source
1	Orange fleshed sweet potato	vitamin A	Kenya Agricultural Research Institute	Sharma *et al.*, (2017) [70]
2	Iron Beans	Zinc and Iron	International Centre for Tropical Agriculture	Sharma *et al.*, (2017) [70]
3	Pearl Millet	Iron	ICRISAT	Schmidt *et al.*, (2015) [68]
4	Wheat	Zinc and Iron	CIMMYT	Saltzman *et al.*, 2013 [61]
5	Zinc Rice	Zinc and Iron	Bangladesh Rice Research Institute	Yang *et al.*, (2011) [73]
6	Golden Rice	vitamin A	International Rice Research Institute	Saltzman *et al.*, (2013) [61]

Table 2: Types of Biofortification in different crops

S. No.	Type of biofortification	Crop name	Source
1	β-Carotene	Cassava, OSP, Maize, Golden rice	Saltzman *et al.*, (2013) [61]
2	Iron	Cowpea, Irish potato, Lentil, Sorghum	Garg *et al.*, (2018) [20]
3	Lysine	Sorghum, Barley, Maize, Canola	Schmidt *et al.*, (2015) [68]
4	Methionine	Groundnut, Maize, Soyabean	Choudhary *et al.*, (2020) [14]
5	γ-Linolenic acid	Soyabean, Canola, Mustard	Schmidt *et al.*, (2015) [68]
6	Zinc	Iron Beans, Zinc rice, Wheat	Yang *et al.*, (2011) [73]
7	Carotenoids	Cassava, Beans, Maize	Saltzman *et al.*, (2013) [61]

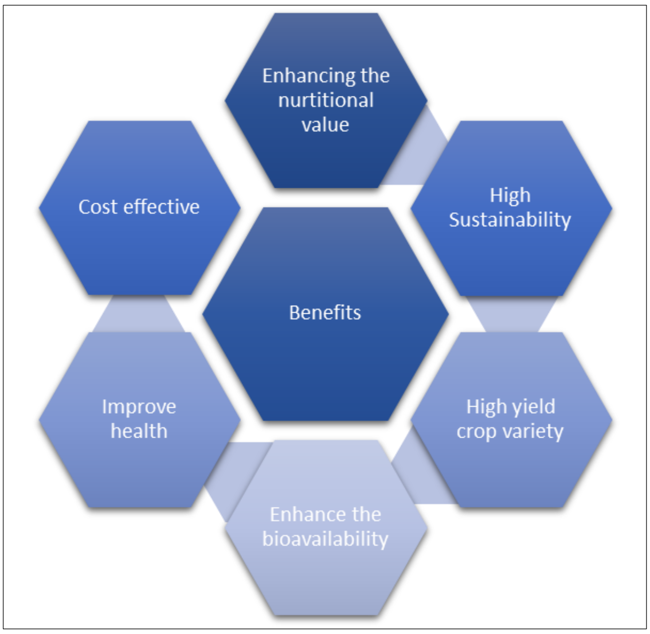


Fig 1: Benefits

Conclusion

Biofortification is the most sustainable and cost-effective approach of enriching the nutritional content of crops to alleviate malnutrition and enhance the health of impoverished people around the world. Plant breeding, transgenic technology, and mineral fertiliser applications all have considerable potential for addressing micronutrient deficiencies. Despite conventional breeding, transgenics are given greater weight to biofortify crops, which face regulatory and consumer acceptance challenges. Only 2.4 percent of transgenic biofortified rice varieties have been released, indicating that these crops continue to confront regulatory challenges. To create and provide biofortified varieties, the produced varieties must be incorporated in the seed chain to boost the formal and informal farming systems. This would result in a lower hunger index and improved nutrition security for a huge number of people. In comparison to the traditional method of introducing numerous biofortified crops or cultivars with a single vitamin to eradicate all kinds of malnutrition, multi-biofortification looks to be an efficient means of introducing multiple micronutrients simultaneously into a cultivar.

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