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Traditional to Modern Approaches for Agronomic Biofortification of Food Crops with Zn and Fe: A Review

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ABSTRACT: Biofortification is an emerging, promising, affordable, and long-term method of providing nutritional security to a population with limited access to a variety of diets and any other micronutrient interventions. The efficacy of agronomic biofortification has been further enhanced by the advent of high-specialty fertilizers such as water-soluble, chelated, and nano-fertilizers, which have greater nutrient translocation to the consumable portions of a crop plant and high nutrient absorption efficiency. The significance of agronomic biofortification has been further enhanced by a number of novel strategies, including foliar application, soilless activation, nutripriming, and mechanized application methods. The agronomic biofortification significance for global nutritional & food security has been reinforced by these recent technical developments as well as a growing understanding of mineral micronutrient nutrition. The review emphasizes the progress made in the area of agronomic biofortification through the development of new, improved forms of fertilizer and cutting-edge methods which improves crop plants' ability to use micronutrients.

Keywords: Biofortification, specialty fertilizers, nutritional security, nutrient uptake efficiency.

INTRODUCTION

Good nutrition is a key to healthy life and it mainly depends on sustainable agriculture (Athar *et al*., 2020). In order to maintain good mental & physical health and lead fulfilling lives, humans need a balance of nutrients. Sodium, calcium, potassium, phosphorous, magnesium, sulfur, and chlorine are mineral elements that are categorized as essential nutrients that the human body needs in trace amounts. The remaining group of vital nutrients, known as micronutrients, are those that the body needs in minuscule amounts and involve zinc, iron, copper, manganese, selenium, cobalt, iodine, molybdenum, and nickel (Table 1) Prashanth *et al.(*2015). All of these nutrients are essential to human health and development, both physically and mentally (White et al. 2005). Even mild to moderate micronutrient deficiencies can lead to serious health problems for humans, including poorer immune function increased susceptibility to infections, growth failure, cognitive decline, and eventually lower productivity (Tulchinsky, 2010). Worldwide, micronutrient deficiencies impact approximately 38% of pregnant mothers and 43% of preschool-aged children. According to reports, over 30% of people on the planet are anemic and experiencing hidden hunger (Stevens *et al*., 2013). Compared to developed countries, developing countries have a higher prevalence of anemia.

According to the Times of India (2021), a report has been published based on a world wide survey of 220 healthcare practitioners (doctors & nutritionists), 70percent of the average Indian diet lacks appropriate nutrition. Additionally, the survey revealed that the two vitamins most commonly deficient in the average daily diet nationwide are vitamin B12 and D3, which are followed by the iron, zinc, folic acid, calcium, and vitamin C. Furthermore, it was suggested in the Indian Food Composition (Longvah *et al*., 2017) report by the National Institute for Nutrition (NIN), Hyderabad, that over the past thirty years or so, a large number of our food items have rapidly lost their nutritional value. For instance, the amount of carbohydrates in whole wheat has decreased by 9% and in bajra (Pearl Millet) by 8.5%. Similarly, the essential protein component of pulses is being lost; it has decreased by 10.4% in masoor (whole brown) and 6.12% in moong (whole green). On the other hand, potatoes have less zinc, magnesium, and thiamine (vitamin B1). In cabbage, micronutrients like iron, thiamine, magnesium, and zinc have decreased by as much as 41–56%. Iron, zinc, and thiamine have all decreased by 66–73 percent in red tomatoes. Apples and green tomatoes have lost 60% and 76.6 percent of their iron, respectively. We now prefer coarse grains because they are full of micronutrients, due in large part to our growing health consciousness and concerns about the gluten content of wheat and rice. Based on an analysis, pearl millet, barley, sorghum, and maize now have lower levels of thiamine, iron, and riboflavin.

A practical, affordable, and long-term method of increasing the amount of vital micronutrients, minerals, and vitamins (involving trace elements) in food is fortification. This enhances the food's nutritional value and lowers the likelihood of health issues for the general public. On the other hand, biofortification is the process of enhancing food crops' nutritional value through the use of contemporary biotechnology, conventional plant breeding, or agronomic techniques (World Health Organization, 2019). Unlike conventional fortification, which uses manual methods during crop processing, biofortification goals to raise levels of nutrients in crops during the growth of plants.

Moreover, from an economic perspective, industrial fortification of processed foods appears to be an expensive strategy with only negligible advantages for micronutrients like zinc & iron (Bromage *et al.,* 2018). This problem could be solved by biofortification, but the best approach to encourage biofortification would be to include it in a wide range of sustainable, plant-based nutritional strategies (FAO, 2017). According to reports, biofortified crops significantly improve human health by increasing micronutrient intake (Praharaj *et al.,* 2021).

The simplest way to increase the microelements levels in the crops has to be known to be agronomic biofortification, which aims to supply micronutrients which could be directly absorbed by plant by applying mineral and/or foliar fertilizers and/or improving the solubilization and mobilization of mineral elements in the soil. Furthermore, numerous reports demonstrate that biofortification not only enhances plants' micronutrient content but also significantly influences the creation of the any other compounds with nutritional qualities (Newman *et al.,* 2021).

The main disadvantages of biofortification via genetic engineering or conventional plant breeding are that the products are not approved in all nations and that it takes a long time to develop. In contrast, agronomic biofortification is the simplest, quickest, and most widely recognized approach to enriching food with micronutrients, vitamins, folic acids, and other essential elements while still reaching the poorest rural populations. For instance, compared to their non-AMF treatments, the integrated application of arbuscular mycorrhizal fungi (AMF), P, and irrigation regimes on okra increased the average total uptake of N, P, K, Ca, B, and Mo by 8, 24, 5, 14, 8, and 40 percent, correspondingly (Kumar, 2012). Alternatively, genetic biofortification—a crop types engineered to naturally absorb more mineral micronutrients through the soil—means that the grower does not necessarily need to apply the micronutrient in order for it to be fortified. However, agronomic biofortification would also be crucial in these circumstances. Crop varieties fortified with genetic engineering would scavenge soil micronutrients, which are also a finite and exhaustible resource. If not right away, agronomic biofortification would need to be added after a few years to sustain source-sink linkage in genetically enhanced crops. The review discussed the developments in cutting-edge methods that improve crop plants' ability to absorb micronutrients, which can increase the effectiveness of agronomic biofortification.

Zn AND Fe FROM SOIL TO PLANT

Plants primarily absorb nutrients through their roots, and the rhizosphere's local conditions can affect how bioavailable zinc and iron are to the plants. Numerous elements in the soil and plants influence how much zinc and iron plants take up. The ionic form and soil concentration of zinc and iron are the most significant factors influencing uptake. The concentration of competitive anions, soil mineralogy, pH, and clay content are other significant factors that affect how much zinc and iron plants accumulate.

Zn is mostly taken up by plants from the soil as the divalent cation Zn^{2+}. Plants mainly take up zinc from the soil through their roots through a process called facilitated diffusion, which is aided by transporters and membrane potential (Marschner, 2012). However, plant roots can occasionally also absorb organic ligand-Zn complexes. The uptake involves two potential physiological mechanisms, which vary based on the ligand released by the roots of plants. Consequently, mechanism I entail the organic acids efflux, solvents, and H^+ ions, which enhance Zn-complex absorption & liberate Zn^{2+} ions for absorption by the root epidermal cells. In contrast, mechanism II involves the phyto-metallophores outflow, that combines with zinc to form complex compounds that are subsequently taken up by root epidermal cells. However, according to Chatterjee et al. (2018), this absorption process (i.e., method II) is only available for cereal roots. These mechanisms necessitate differences in Zn content between root cell membranes and the involvement of molecules of water as the solvents.

H^+ ATPase regulates the fast polarization of a root plasma membrane, which is the main factor causing the uptake of Zn $^{2+}$. The result of ATP hydrolysis is the strong pumping of H^+ ions out of the cell by the H^+ ATPase. By lowering the soil pH and hyperpolarizing the root plasma membrane, H^+ production in the rhizosphere promotes cation absorption (Kamaral *et al.,* 2022).With the aid of particular transporters found at the pericycle, xylem loading facilitates the root-to-shoot Zn^{2+} transport. Different strategies are used by plants to absorb different amounts of nutrients. For instance, the acquisition of Fe in dicot and non-graminaceous species "on the basis of Fe-limiting environment concept. In these circumstances, an active proton pump generates more Fe^{+2} & Fe transporter through ferric chelate reductase, increasing the solubility of Fe^{+3}. In contrast, the tactic used by graminaceous monocots on the basis of phytosiderophores releases from the roots, which chelate with Fe^{+3} and then taken up by particular transporters" (Hell and Stephan 2003).

Transpirational forces draw the micronutrients up and deposit them in the plant's leaves after they have passed through the xylem. The leaves function as a sink for carbohydrates & nutrients up until this point. When a plant grows further, its leaves change from being a sink (a source of carbon and nutrients) to a source (a sink of carbon and nutrients) when the amount of carbon stored in photosynthesis exceeds the amount needed for the respiration & growth. The xylem carries nutrients through the roots to leaves, while the phloem facilitates additional translocation of the nutrients through leaves to the other sections (such as grain, fruit, etc.). When foliar fertilizer is applied (sprayed), micronutrients enter through the cuticle & stomata on surface of the leaf and then accumulate directly at the phloem. This application method can be more effective from a biofortification standpoint because the pathway is shorter than when roots are absorbed. For optimal biofortification, there must be a greater intake of micronutrients, better translocation within the plant, and raised accumulation at portions of edible.

APPLICATION METHODS IN AGRONOMIC BIOFORTIFICATION

Micronutrient deficiencies in plants and people can be addressed by applying micronutrients as fertilizers, which can also enhance the status of these nutrients in the soil. So far, when micronutrients are added to the soil, they get fixed right away and don't easily move to the parts of the plant that are consumed. It is then advised to apply micronutrients using alternative methods, like soluble form foliar sprays. Agronomic biofortification is a cheap and easy tool if certain factors are taken into consideration, like the type of fertilizer, how it is applied, and when it is applied. There are several methods for agronomic biofortification soil application of micronutrient fertilizer, foliar application utilizing nutripriming, diluted fertilizer sprays, and soilless cultivation have been the most popular method of biofortification.

A. Soil application

The most popular way to give crops micronutrients is through soil application. Maqsood *et al.* (2009) found that applying 6 mg/kg of soil zinc fertilizer increased grain zinc concentrations from 51.7% to 69.9%. Compared to broadcasting, the banding placement needs 3 times less micronutrient fertilizer (Sarwar *et al.*, 2017). Although adding zinc to the soil can boost crop yield, it has a lower fertilizer utilization effectiveness and is not as effective at increasing the amount of zinc in grains (Chattha *et al.,* 2017). It is affirmed that applying soil in addition to foliar application is a more efficient and superior method of raising grain yield than applying either substance by itself. Due to the excessive accumulation of wasted micronutrients, this method pollutes soil over time and has low micronutrient use efficiency and cost-effectiveness. Because plants have a strong tendency to concentrate zinc under conditions of water scarcity, applying zinc through the soil did not increase the concentration of zinc in grain under these circumstances (Gomez-Coronado *et al.,* 2016). Despite being the most widely used technique for applying micronutrients to crops, soil application has primarily been investigated for increasing crop productivity as opposed to biofortification.

B. Foliar application

The most widely used method of micronutrient biofortification is foliar application because it is easy to implement, more fertilizer-efficient, needs fewer infrastructure, and doesn't need the technical know-how of methods like soil-less cultivation & nutripriming. Foliar application is preferable to soil application because there is very little micronutrient loss and the nutrients are absorbed by the tissue of a plant directly (Johnson *et al.,* 2005). According to Zou *et al.* (2012), zinc foliar feeding has been the best method for raising the zinc content of grains. By analyzing metadata from published literature, Joy *et al.* (2015) concluded that foliar application is a more effective way to get zinc into rice, maize, and wheat grains than soil application.

When it comes to utilizing nutrients efficiently and quickly treating visual deficiency issues, foliar application of nutrients appears to be more beneficial than soil amendments (Fageria *et al.,* 2009). For biofortification of a grain, foliar application later in the vegetative stages is preferable to foliar application early (Yilmaz *et al.,* 1997). More than other prior applications, foliar zinc application after flowering and in the initial stages of dough & milk increased grain zinc content (Phattarakul *et al.,* 2012). Without affecting biological yield, foliar Zn spraying increased test weight & grain protein content in the alkaline soils (Khattak *et al.*, 2015). $FeSO_4$ foliar sprayed at the time of anthesis increased the gluten and grain protein content in the durum wheat, particularly when seeded at a 125kg ha^{-1} rate (Melash *et al.*, 2016).

Since there is less water available for the procedure of irrigation & the solubilization of soil-applied fertilizer in arid along with the semi-arid climates, foliar treatment is acknowledged as a crucial strategy for addressing micronutrient deficiencies in crops (Chapagain & Wiesman 2004). However, foliar application should only be regularly used when it has proven to be more beneficial than soil application. According to Narwal *et al.* (2012), 14 winter wheat varieties had higher levels of Zn and Fe after receiving foliar treatment. Given that applying soil has the drawback of causing micronutrients to fix in calcareous and alkaline soils (Alloway, 2008). In such cases, the foliar application creates more sense. According to Zhang *et al.* (2012), foliar zinc treatment has been an efficient way to provide people with more dietary zinc from products made from biofortified wheat because it has been much more successful than the soil zinc application at enriching wheat grain containing zinc. In addition, a study conducted on mungbean revealed that the concentration of zinc in the grain was approximately 1.7 times higher (Haider *et al.*, 2018a) following the application of 1.0 percent zinc sulfate solution than when zinc was applied to the soil at a 10mg kg^{-1} concentration (Haider *et al.,* 2008). It has been important to remember, though, that effective foliar fertilization necessitates greater leaf area in order to improve applied micronutrient adsorption.

Additionally, Zinc sulfate applied at the sowing along with foliar Zn applied during flowering & stages of pod formation produced the best fertilizer effect for chickpeas (Pal *et al.*, 2019). Zn-phytate interaction, when applied through various methods, is an important factor determining Zn's bioavailability. Consequently, adding enough zinc to the soil increases grain yield, but adding zinc as foliage during the booting stage increases zinc concentration & bioavailability in the wheat grain (Hussain *et al.*, 2012). Additionally, some authors proposed that by applying the Zn and Fe together in soil & foliar fertilizers (Rivera-Martin *et al.*, 2020) and fertilizing by the amendments like salicylic acid or biochar (Smoleń *et al.*, 2019) enhanced the effectiveness of microelement accumulation in the crops while applying together rather than separately.

C. Nutripriming

Soaking seeds in a nutrient-rich solution prior to planting is known as nutripriming or seed-priming (Raj and Raj 2019). The pre-sowing hydration technique known as "seed priming" permits seeds to carry out their pre-germination processes without radical protrusion (Bradford, 1986). Compared to dry seeds, primed seeds have a higher potential for uniform stand establishment (Farooq *et al.*, 2006). The main goals of seed priming have been to improve yield and facilitate germination, root system development, and seedling establishment (Farooq *et al.*, 2019). On the other hand, nutripriming has also been linked to higher grain nutrient content, according to some researchers. Zinc-nutripriming chickpea with $ZnSO_4$ (0.4 percent) increased grain Zn content by 29percent (Harris *et al.*, 2008) and wheat by 12% to 15% (Praharaj *et al.*, 2019). Because micronutrients have been added to the seeds prior to sowing, seed priming also has the advantage of being cost-effective for farmers to implement (Harris *et al.*, 2008).

Micronutrient seed priming increases crop yield and micronutrient content while being economical and environmentally benign. Seldom has it been discovered that seed priming is ineffective (Farooq *et al.*, 2012). After nutripriming with $ZnSO_4$ & $ZnCl_2$, correspondingly, at a rate of 1.25g Zn kg^{-1} seed, the grains Zn content has been raised from 21-35 percent, and production of grains increased by 33–55 percent Rehman and Farooq 2016). When weighed against soil application, seed priming was also more economical, with benefit-cost ratios from seed priming being 8 and soil application being 360, respectively (Harris *et al.*, 2005). But priming chickpea in the diluted $ZnSO_4$ (0.05percent) solution proved successful, yielding 10-122 percent more (average value of 48percent from 9 trials) than unprimed seeds, with a benefit: cost ratio of 1500 (Harris *et al.*, 2005).

Choukriti *et al.* (2022) state that seed priming in all forms, including hydro-priming, encourages the germination of seed. Zinc priming was used to increase grain yield while enriching the seeds with this element. In particular, the yield and Zn content of seedlings treated with 0.5 percent Zn sulfate for 24 hours increased by 47 percent and 15 percent, respectively. Similarly, Zn treatment of the seeds significantly increased rice growth and grain yield, and this was more economical and practical than applying the zinc to the soil or not applying it at all (Slaton *et al.*, 2001). Many factors, including genotype, crop type, nutrient priming duration, priming solution osmotic potential, and environmental conditions, influence how effective seed priming is (Waqas *et al.*, 2019). A South Asian experiment found that seed priming increases crop growth and productivity (Harris *et al.*, 2007). According to Harris *et al.* (2018), seed priming with a 0.05 percent zinc solution raises the yield & concentration of zinc in the grain by 19 and 29%, respectively. In addition, farmers may not be as familiar with nutripriming techniques because they entail technical aspects of priming methodology. The seeds would need to be stored optimally or sown right away because priming could shorten their shelf life (Murphy, 2017).

D. Soilless cultivation

Soilless cultivation is the approach of growing plants without soil as a rooting medium. In soil-less crops, the fertilizers which are to be supplied to the crops are dissolved in the appropriate concentration in the irrigation water and that resultant solution is named as nutrient solution. Soil-less cultivation includes Hydroponics, Aquaponics, and Aeroponics. The ability to regulate pH, water availability, and nutrient concentrations in the root zone (Gruda, 2009)—as well as the efficiency with which root contact with nutrient supply can be maximized—are among the special advantages of soilless culture techniques (Treftz and Omaye 2016). Moreover, soilless cultivation disregards soil constraints like fertility of soil and transmission of disease in favor of extending the cultivation cycle and enabling year-round production (Rouphael and Kyriacou 2018). Tomasi *et al.* (2015) list the absence of weeds, low labor requirements, ease of processing & harvesting, and an automated system for the maintenance of plant as additional advantages of soilless agriculture. According to research, soilless farming can effectively raise the zinc and selenium content of “lettuce (*Lactuca sativa* L.) (Sahin, 2020) and the zinc content of white cabbage (*Brassica oleracea* L.) (Barrameda-Medina *et al.*, 2017)”. Fe deficiency in cherry tomatoes can be effectively treated and fruit quality improved through biofortification (Buturi *et al.*, 2022). Even though soilless cultivation is extremely effective and environmentally friendly, it requires infrastructure growth which is out of reach for several regions.

E. Chelated fertilizers

Chelated fertilizers have been those types of fertilizers where the nutrient ion is shielded from oxidation, precipitation, and immobilization by a large organic molecule called a Ligand/Chelator. It has been demonstrated that chelated fertilizers offer superior nutrient protection against soil conditions (pH, moisture, etc.) that can lead to nutrient immobilization or loss through leaching, precipitation, or oxidation. As a result, plants absorb chelated nutrients more readily and lose less of them. Chelated micronutrients are superior to organic and biofertilizers due to their high nutrient content and increased efficiency over inorganic micronutrient fertilizers. Chelated nutrients have lessened loss to the environment. In a greenhouse study, Zhao *et al.* (2019) discovered that Zn-EDTA fertilization, even with a lower treatment volume, achieved greater Zn biofortification as compared to $ZnSO_4.7H_2O$ fertilization.

Content of zinc in wheat has been raised by the foliar application of Zn-consisting salts & Zn chelates (e.g., $ZnSO_4$, Zinc-EDTA, generally @ 0.5-0.7kg/ha) (Zhao *et al.*, 2014). As per the findings of Shivay *et al.* (2016a), the application of Zn-EDTA three times on leaves during the booting, tillering, and grain-filling stages led to notable improvements in growth, yield attributes, concentration, and uptake of Zn compared to $ZnSO_4.H_2O$. According to Márquez-Quiroz *et al.* (2015), applying Fe-EDDTA complexes is a more efficient method of raising the amount of Fe in the cowpea bean seed than using an inorganic form.

F. Biofertilizers

According to Bhardwaj *et al*. (2014), biofertilizers have been "microbial inoculant preparations made of microorganisms that aid in enhancing the productivity & development of the host plant. It is advantageous to combine Zn and Fe with the application of AMF and PGPR (Plant Growth-Promoting Bacteria)". Through a number of processes, such as exchange reactions, chelation, acidification, and the release of organic acids, PGPR mobilizes the nutrients (Triticum *et al*., 2015). Additionally, the mechanism is solely dependent on the micronutrients chemical form, such as phosphates, oxides, or carbonates, and the application of PGPR. Bacillus is the most widely used plant growth-promoting bacterium (PGPR) for microelement biofortification. Maize was enriched in zinc using *Bacillus aryabhattai* and *B. subtilis* (Mumtaz *et al.*, 2018).

The Zn level in lettuce was raised by inoculating the fungus *Piriformospora indica* with zinc, as investigated by Padash *et al*. (2016). When Zn was inoculated with *Rhizophagus irregularis* above 150mg $Znkg^{-1}$ of soil, a positive impact on the grain Zn concentration has been noted (Tran *et al.,* 2019). The *Anabaena* sp. & *cyanobacteria Azotobacter* sp., as well as wheat (Ramesh *et al*., 2014), *Bacillus aryabhattai* (Prasanna *et al*., 2015), and the soybeans (*Glycine max* L.) (Ramesh *et al.*, 2014), facilitate zinc biofortification in corn grains. It has been discovered that AMF improves root development and guarantees N, P, Cu, Zn, Fe, and Mn uptake. *Rhizophagus irregularis* raises the concentrations of primary metabolites & minerals sucas Mn, Fe, Zn, and Cu in the medicinal plants like Petroselinum hortense & Mentha pulegium (Gashgari *et al*., 2020). Sharma & Johri reported that *Pseudomonas chlororaphis* & *Pseudomonas* spp. isolated from maize enhanced Fe uptake, plant growth, germination, and output of crop (2003). Plants cannot absorb ferric forms of iron (Fe^{3+}) due to their extremely low solubility; however, microorganisms secrete siderophores, which are Fe-chelating compounds that help microelements be absorbed at varying pH levels.

G. Nanofertilizers

According to Bhardwaj *et al.* (2022), nano fertilizers have been fertilizer forms in which the active ingredients have been adsorbed, dispersed, entrapped, or encapsulated at host material. These particles, micelles, or pockets range in size from 1 to 100 nm. A well-liked substitute technique for enhancing nutrition is wheat crop nano-biofortification (Khan *et al.,* 2021). Tailored fertilizers known as nanofertilizers have the potential to completely transform the way we currently farm (Rai *et al.*, 2018). Nanofertilizers have been sophisticated delivery systems which are simple to use, safe, and target-bound. Most polymeric-type fertilizers have a higher area of surface to volume ratio, which makes nano-formulations more effective, slow-releasing, and efficient sources of nutrients for crops (Fig. 1). As a result, nano-fertilization provides a platform for an innovative and sustainable nutrient delivery system which could investigate a plant's nanoporous surface.

Plant species & chemical characteristics of the nanomaterials, like size, composition, and concentration, are key determinants of the effectiveness of nanofertilizers (Thakur *et al.*, 2018). Since nano-fertilizers have been designed to potentially compensate for a specific nutrient deficit, biofortification with nano-nutrients appears to be a promising avenue to pursue. The plant will grow and store these nutrients in its edible parts with the help of these fertilizers (Li *et al.*, 2016).

According to "Dapkekar *et al.* (2018), even though zinc complexed chitosan nanoparticles were used at a 10-fold lower concentration, grain Zn enrichment has been seen to rise by approximately 36percent with Zn-CNP nano-carrier & approximately 50percenthaving $ZnSO_4$. The 2 durum wheat varieties (MACS 3125 & UC 1114) have been treated with Zn-CNP (40mg L^{-1}) & conventionally applied $ZnSO_4$ (0.2 percent; 400mg L^{-1} zinc).A foliar treatment of 100mg L^{-1} of the ZnOnano fertilizer caused Zn concentrations of 100–150mg kg^{-1} dry weight in shoot & root tissues & 45mg kg^{-1} in wheat grain", according to Hussain et al. (2021). This rise in the content of Zn in the plant has several parts. Hussain *et al.* (2019) found that grain Fe content was higher (110mg kg^{-1}) with foliar application of Fe nanofertilizer than with soil application (90mg kg^{-1}). However, shoot Fe concentrations were higher with soil application of Fe nanofertilizer than with foliar spray.

When citrate-coated nano Fe_2O_3& Fe_2O_3 (conventional form) have been applied to the plants of soybean, Alidoust and Isoda (2013) discovered that no phytotoxic effects were seen. Compared to conventional Fe_2O_3, nano-Fe_2O_3 had a more stimulating impact on the growth of the root. Nanoparticle properties such as size, chemical configuration, stability, and concentration affect the plant species that absorb, translocate, and accumulate the particles. Reducing the fertilizer particles size applied is intended to provide the "appropriate amount of nutrients" at the "appropriate location" and "appropriate time." Furthermore, smaller particles have a higher specific surface area, which increases the area in which fertilizers come into contact with plants. This increases plant nutrient uptake relative to when commercial fertilizers are applied.

Table 1: Essential macro and micro nutrients required for good human health.

Macronutrients			Micronutrients	
Macro-minerals	**Amino acids (Essentials)**	**Fattyacids (Essential)**	**Micro-minerals**	**Vitamins**
K	Histidine	Linoleic acid	Fe	A
Ca	Isoleucine	Linolenic acid	Zn	D
Mg	Leucine		Cu	K
S	Lysine		Mn	E
P	Methionine		Se	C
Na	Phenylalanine		Mo	B_1
Cl	Threonine		Co	B_2
	Tryptophan		Ni	B_3
			I	B_5
				B_6
				B_7
				B_9
				B_{12}

Source: Prashanth *et al*. 2015

Fig. 1. Nano fertilizers benefits the soil as well as plant.

CONCLUSIONS

Growers can readily adopt agronomic biofortification because it is easy to follow. Farmers and growers typically don't care for agronomic biofortification because it doesn't directly increase crop yield, even though it has clear financial benefits. With the development of many kinds of specialty fertilizers, such as chelated fertilizers, nano-fertilizers, water-soluble fertilizers, and biofertilizers, which have better nutrient translocation to the consumable plant parts and higher plant nutrient use efficiency, the efficacy of agronomic biofortification has increased recently. Future research should concentrate heavily on agronomic biofortification in order to ensure that crops are enriched with micronutrients and combat hidden hunger.

REFERENCES

Alidoust, D. and Isoda, A. (2013). Effect of γFe_2O_3 nanoparticles on photosynthetic characteristic of soybean (*Glycine max* (L.) merr.): foliar spray versus soil amendment. *Acta physiologiae plantarum, 35*(12), 3365–3375.

Alloway, B. J. (2008). *Zinc in soils and crop nutrition* (Belgium and Paris, France: published by IZA and IFA Brussels). Available at: http://www.topsoils.co.nz/wp-content/uploads/2014/09/Zinc-in-Soils-and-Crop-Nutrition-Brian-J.-Alloway.pdf (Accessed 13.12.2021).

Athar, T., Khan, M. K., Pandey, A., Yilmaz, F. G., Hamurcu, M., Hakki, E. E. and Gezgin, S. (2020). Biofortification and the involved modern approaches. *J Elem*, *25*, 717–731.

Barrameda-Medina, Y., Blasco, B., Lentini, M., Esposito, S., Baenas, N., Moreno, D. A., & Ruiz, J. M. (2017). Zinc biofortification improves phytochemicals and amino-acidic profile in *Brassica oleracea* cv. Bronco. *Plant science*, *258*, 45-51.

Bhardwaj, A. K., Geeta, A., Raj, K., Lamy, H., Hadi, P. A. and Poonam, J. (2022). Switching to nanonutrients for sustaining agroecosystems and environment: the challenges and benefits in moving up from ionic to particle feeding. *J. Nanobiotechnology*, *20*(1), 1–28.

Bhardwaj, D., Ansari, M. W., Sahoo, R. K. and Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell factories*, *13*, 1–10.

Bradford, K. J. (1986). Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. *Hort Science*, *21*, 1105–1112.

Bromage, S., Ganmaa, D., Rich-Edwards, J. W., Rosner, B., Bater, J., and Fawzi, W. W. (2018). Projected effectiveness of mandatory industrial fortification of wheat flour, milk, and edible oil with multiple micronutrients among Mongolian adults. *PloS One*, *13* (8), e0201230.

Buturi, C. V., Coelho, S. R. M., Cannata, C., Basile, F., Giuffrida, F. and Leonardi, C. (2022). Iron biofortification of greenhouse cherry tomatoes grown in a soilless system. *Horticulturae*, *8*(10), 858.

Chapagain, B. P. and Wiesman, Z. (2004). Effect of nutri-Vant-Peak foliar spray on plant development, yield, and fruit quality in greenhouse tomatoes. *Scientia Hortic.*, *102*(2), 177–188.

Chatterjee, S., Mukherjee, D., Sharma, S. and Choudhuri, P. (2018). Managing boron and zinc deficiency in vegetable crops. *Innovative Farming, 3*(2), 72–76.

Chattha, M. U., Hassan, M. U., Khan, I., Chattha, M. B., Mahmood, A., and Chattha, M. U. (2017). Biofortification of wheat cultivars to combat zinc deficiency. *Front. Plant Sci.*, *8*, 1–8.

Choukri, M., Aziz, A., Rachid, B., Omar, H. A. E., Octavian, P., and Fehmi, B. (2022). Zn application through seed priming improves productivity and grain nutritional quality of silage corn. *Saudi J. Biol. Sci.*, *29*(12), 103456.

Dapkekar, A., Deshpande, P., Oak, M. D., Paknikar, K. M. and Rajwade, J. M. (2018). Zinc use efficiency is enhanced in wheat through nano fertilization. *Sci. Rep.*, *8*(1), 1–7.

Fageria, N. K., Filho, M. P. B. Moreira, A. and Gulmaraes C. M. (2009). Foliar fertilization of crop plants. *J Plant Nutr, 32*, pp. 1044-1064.

FAO (2017). Nutrient-sensitive agriculture and food systems in practice. In: *Food and agriculture organization of the unitednations* (Rome). Available at: https://www.fao.org/3/i7848e/i7848e.pdf (Accessed May 10, 2022).

Farooq, M., Basra, S. M. A. and Hafeez, K. (2006). Seed invigoration by smohardening in fine and coarse rice. *Seed Sci. Technol*., *34*, 181-186.

Farooq, M., Cheema, Z. A., and Wahid, A. (2012). Seed priming with boron improves growth and yield of fine grain aromatic rice. *Plant Growth Regul.*, *68*(2), 189–201.

Farooq, M., Usman, F. Nadeem, H. U. and Rehman, A. (2019).Wahid, S.M.A. Basra, K.H.M. Siddque Seed priming in field crops: Potential benefits, adoption and challenges. *Crop Pasture Sci.*, *70*(9), 731-771.

Gashgari, R., Selim, S., Abdel-Mawgoud, M., Warrad, M., Habeeb, T. H. and Saleh, A. M. (2020). Arbuscular mycorrhizae induce a global metabolic change and improve the nutritional and health benefits of pennyroyal and parsley. *Acta Physiologiae Plantarum*, *42*(6), 1–11.

Gomez-Coronado, F., Poblaciones, M. J., Almeida, A. S. and Cakmak, I. (2016). Zinc (Zn) concentration of bread wheat grown under Mediterranean conditions as affected by genotype and soil/foliar Zn application. *Plant Soil*, *401*, 331-346

Gruda, N. (2009). Do soilless culture systems have an influence on product quality of vegetables? *J. Appl. Bot. Food Qual.*, *82,* 141–147.

Haider M.U., Farooq M., Nawaz, A. and Hussain, M. (2018a). Foliage applied zinc ensures better growth, yield and grain biofortification of mungbean. *Int J Agric Biol*, *20*, 2817–2822.

Haider, M.U., Hussain, M., Farooq, M. and Nawaz, A. (2018b). Soil application of zinc improves the growth, yield and grain zinc biofortification of mungbean. *Soil Environ*, *37*, 123–128.

Hell, R. and Stephan, U. W. (2003). Iron uptake, trafficking and homeostasis in plants. *Planta, 216,* 541–551.

Harris, D., Rashid, A., Arif, M., and Yunas, M. (2005). Alleviating micronutrient deficiencies in alkaline soils of the North-West Frontier Province of Pakistan: On-farm seed priming with zinc in wheat and chickpea. In: P. Andersen, J.K. Tulad-har, K.B. Karki, S.L. Maskey (eds.). Micronutri-ents in South and South East Asia, pp. 143-151. Proceedings of an International Workshop held in Kathmandu, Nepal, 8-11 September, 2004.

Harris, D., Rashid, A., Miraj, G., Arif, M. and Yunas, M. (2008). ‘On-farm’ seed priming with zinc in chickpea and wheat in Pakistan. *Plant Soil, 306*, 3-10.

Hussain, A., Ali, S., Rizwan, M., Rehman, M. Z., Qayyum, M. F., and Wang, H. (2019). Responses of wheat (*Triticum aestivum*) plants grown in a cd contaminated soil to the application of iron oxide nanoparticles. *Ecotoxicology Environ. Saf.*, *173,* 156–164.

Hussain, A., Rizwan, M., Ali, S., Rehman, M. Z. U., Qayyum, M. E., and Nawaz, R. (2021). Combined use of different nanoparticles effectively decreased cadmium (Cd) concentration in grains of wheat grown in a field contaminated with cd. *Ecotoxicology Environ. Saf.*, *215*, 112139.

Hussain, S., Maqsood, M. A., and Rengel, Z. (2012). Biofortification and estimated human bioavailability of zinc in wheat grains as influenced by methods of zinc application. *Plant Soil*, *361*, 279–290.

Johnson, S. E., Lauren, J. G., Welch, R. M. and Duxbury J. M. (2005). A comparison of the effects of micronutrient seed priming and soil fertilization on the mineral nutrition of chickpea (*Cicer arietinum*), lentil (Lens culinaris), rice (*Oryza sativa*) and wheat (*Triticum aestivum*) in Nepal. *Exp Agric*, *41*, 27-448.

Joy, E. J. M., Stein, A. J., Young, S. D., Ander, E. L., Watts, M. J., and Broadley, M. R. (2015) Zinc-enriched fertilisers as a potential public health intervention in Africa. *Plant Soil*, *389*, 1–24.

Kamaral, C., Neate, S. M., Gunasinghe, N., Milham, P. J., Paterson, D. J. and Kopittke P. M. (2022). Genetic biofortification of wheat with zinc: Opportunities to fine-tune zinc uptake, transport and grain loading. *Physiol. Plant*, *174*(1), e13612.

Khan,,. M. K., Pandey, A., Hamurcu, M., Gezgin, S., Athar, T., and Rajput, V. D. (2021). Insight into the prospects for nanotechnology in wheat biofortification. *Biology*, *10*(11), 1123.

Khattak, S. G., Dominy, P. J., Ahmad, W. (2015). Effect of Zn as soil addition and foliar application on yield and protein content of wheat in alkaline soil. *J. Natl. Sci. Found.*, *43*(4), 303–312.

Kumar, A. (2012). Phosphorus and rain-harvested water economy through vesicular arbuscular mycorrhizae (VAM) in okra–pea sequence [Ph.D. thesis]. Palampur: CSK HPKV.

Li, J., Hu, J., Ma, C., Wang, Y., Wu, C., and Huang, J. (2016). Uptake, translocation and physiological effects of magnetic iron oxide (γ-Fe2O3) nanoparticles in corn (*Zea mays* L.). *Chemosphere*, *159*, 326–334.

Longvah, S. T., Ananthan, R., Bhaskarachary, K. Venkaiah, K. (2017). Indian food Composition Tables. National Institute of Nutrition (Indian Council of Medical Research) Department of Health Research Ministry of Health & Family Welfare, Government of India Hyderabad- 500 007, Telangana State, India.

Marschner, H. (2012). "Marschner's mineral nutrition of higher plants*"* (London: Elsevier/Academic Press).

Maqsood, M. A., Rahmatullah, S. Kanwal, T. Aziz, M. Ashraf (2009). Evaluation of Zn distribution among grain and straw of twelve indigenous wheat (*Triticum aestivum* L.) genotypes. *Pak J Bot*, *41*(1), 225-231.

Melash, A. A., Mengistu, D. K., Aberra, D. A. (2016). Linking agriculture with health through genetic and agronomic biofortification. *Agric. Sci*,. *7* (5): 295–307.

Murphy, D. J. (2017). “Seed treatments,” in *Encyclopedia of applied plant sciences*, 2nd Edititon, vol. 1. Eds.

Thomas, D., Murray, B. G., Murphy, D. J. (Amsterdam, Netherlands: Elsevier), 564–569.

Narwal, R. P., Dahiya, R. R., Malik, R. S., and Kala, R. (2012). Influence of genetic variability on zinc, iron and manganese responses in wheat. *J. Geochemical Explor.*, *121*, 45–48.

Newman, R. G., Moon, Y., Sams, C. E., Tou, J. C., and Waterland, N. L. (2021). Biofortification of sodium selenate improves dietary mineral contents and antioxidant capacity of culinary herb microgreens. *Front Plant Sci.*, *12*, 716437.

Phattarakul, N., Rerkasem, B., Li, L. J., Wu, L. H., Zou, C. Q., and Ram, H. (2012). Biofortification of rice grain with zinc through zinc fertilization in different countries. *Plant Soil*, *361*(1), 131–141.

Pal, V., Singh, G., and Dhaliwal, S. S. (2019) Agronomic biofortification of chickpea with zinc and iron through application of zinc and urea. *Commun Soil Sci Plant Anal*, *50*, 1864–1877.

Praharaj S., Skalicky M., Maitra S., Bhadra P., Shankar T., and Brestic M. (2021). Zinc biofortification in food crops could alleviate the zinc malnutrition in human health. *Molecules*, *26*, 3509.

Praharaj S., Singh R., Singh V. K., and Chandra R. (2019). Yield and grain zinc concentration of wheat as affected by nutri priming and foliar application of zinc. *J. Pharmacognosy Phytochem.*, *8*, 503–505.

Prasanna, R., Bidyarani, N., Babu, S., Hossain, F., Shivay, Y. S., and Nain, L. (2015). Cyanobacterial inoculation elicits plant defence response and enhanced zn mobilization in maize hybrids. *Cogent Food Agric*, *1*(1), 998507.

Prashanth, L., Kattapagari, K. K., Chitturi, R. T., Baddam, V. R., and Prasad, L. K. (2015). A review on role of essential trace elements in health and disease. *J NTR Univ Health Sci.*, *4*, 75–85.

Rai, P. K., Kumar, V., Lee, S., Raza, N., Kim, K. H., and Ok, Y. S. (2018). Nanoparticle-plant interaction: Implications in energy, environment, and agriculture. *Environ. Int.*, *119*, 1–19.

Raj, A. B. and Raj, S. K. (2019). Seed priming: An approach towards agricultural sustainability. *J. Appl. Natural Sci.*, *11*, 227–234.

Ramesh, A., Sharma, S. K., Sharma, M. P., Yadav, N., and Joshi, O. P. (2014). Inoculation of zinc solubilizing bacillus aryabhattai strains for improved growth, mobilization and biofortification of zinc in soybean and wheat cultivated in vertisols of central India. *Appl. Soil Ecol.*, *73*, 87–96.

Rehman, A., and Farooq, M. (2016). Zinc seed coating improves the growth, grain yield and grain biofortification of bread wheat. *Acta Physiologiae Plantarum*, *38*(10), 1–10.

Rivera-Martin, A., Broadley, M. R., and Poblaciones, M. J. (2020). Soil and foliar zinc biofortification of broccolini: effects on plant growth and mineral accumulation. *Crop Pasture Sci*., *71*, 484–490.

Rouphael, Y., and Kyriacou, M. C. (2018). Enhancing quality of fresh vegetables through salinity eustress and biofortification applications facilitated by soilless cultivation. *Front. Plant Sci.*, *9*, 1–6.

Sahin, O. (2020). Combined biofortification of soilless grown lettuce with iodine, selenium and zinc and its effect on essential and non-essential elemental composition. *J. Plant Nutr.*, *44*, 673–678.

Sarwar, N., Imran, M., Shaheen, M. R., Ishaque, W., Kamran, M. A., and Matloob, A. (2017). Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. *Chemosphere*, *171*, 710–721.

Sharma, A. and Johri, B. N. (2003). Growth promoting influence of siderophore-producing pseudomonas strains GRP3A and PRS9 in maize (*Zea mays* L.) under iron limiting conditions. *Microbiological Res.*, *158*(3), 243–248.

Shivay, Y. S., Prasad, R., Kaur, R. and Pal, M. (2016a). Relative efficiency of zinc sulphate and chelated zinc on zinc biofortification of rice grains and zinc use-efficiency in basmati rice. *Proc. Natl. Acad. Sciences India Section B: Biol. Sci.*, *86*(4), 973–984.

Slaton, N. A., Wilson-Jr, C. E., Ntamatungiro, S., Norman, R. J. and Boothe, D. L. (2001). Evaluation of zinc seed treatments for rice. *Agron. J.*, *93*, 152–157.

Smoleń, S., Kowalska, I., Kováčik, P., Halka, M. and Sady, W. (2019). Biofortification of six varieties of lettuce (*Lactuca sativa* L.) with iodine and selenium in combination with the application of salicylic acid. *Front Plant Sci.*, *10*, 143. h

Stevens, G. A., Finucane, M. M., De-Regil, L., Paciorek, C. J., Flaxman, S. R., and Branca, F. (2013). Global, regional, and national trends in haemoglobin concentration and prevalence of total and severe anaemia in children and pregnant and non-pregnant women for 1995–2011: a systematic analysis of population-representative data. *Lancet Glob Health*, *1*(1), e16–25.

Thakur, S., Thakur, T., and Kumar, R. (2018). Bio-nanotechnology and its role in agriculture and food industry. *J. Mol. Genet. Med.*, *12*,1–5.

Times of India (2021). Average Indian diet has insufficient nutrition: study. TIMES OF INDIA. COM/ Updated: Sep 8, 2021.

Tomasi, N., Pinton, R., Dalla, L., Cortella, G., Terzano, R., and Mimmo, T. (2015). Trends in food science & technology new 'solutions' for floating cultivation system of ready-to-eat salad: A review. *Trends Food Sci. Technol.*, *46*, 267–276.

Treftz, C., and Omaye, S. T. (2016). Hydroponics: Potential for augmenting sustainable food production in non-arable regions. *Nutr. Food Sci.*, *46*, 672–684.

Tulchinsky, T. H. (2010). Micronutrient deficiency conditions: global health issues *Public Health Rev.*, *32*(1), 243-255.

Waqas, M., Korres, N. E., Khan, M. D., Nizami, A., Deeba, F., and Ali, I. (2019). Priming and pretreatment of seeds and seedlings (Singapore: Springer).

White, J., and Broadley, M. R. (2005). Biofortifying crops with essential mineral elements. *Trends Plant Sci*., *10*, 586-593.

World Health Organization (2019). Biofortification of Staple Crops. Available from: https://www.who.int/elena/titles/biofortification/en/

Yilmaz, A., Ekiz, H., Torun, B. I., Gultekin, S., Bagci, S. A., and Cakmak, I. (1997). Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. *J. Plant Nutr.*, *20*(4-5), 461–471.

Zhao, A., Mei, S. Y., Wang, B. and Tian, X. (2019). Effects of $ZnSO_4$ and zn-EDTA applied by broadcasting or by banding on soil zn fractions and zn uptake by wheat (*Triticum aestivum* L.) under greenhouse conditions. *J. Plant Nutr. Soil Sci.*, *182*, 307–317.

Zhao, A. Q., Tian, X. H., Cao, Y. X., Lu, X. C., and Liu, T. (2014). Comparison of soil and foliar zinc application for enhancing grain zinc content of wheat when grown on potentially zinc deficient calcareous soils. *J. Sci. Food Agric.*, *94*, 2016–2022.

Zou, C. Q., Zhang Y. Q. and Rashid, A. (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil, 361*, 119–130.

Zhang, Y. Q., Sun, Y.X., Ye, Y.L., Karim, M.R., Xue, Y. F., and Yan, P. (2012). Zinc biofortification of wheat through fertilizer applications in different locations of China. *Field Crops Res., 125,* 1–7.

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