The Pharma Innovation Journal 2022; 11(7): 1669-1674

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(7): 1669-1674

www.thepharmajournal.com
Received: 11-05-2022
Accepted: 15-06-2022

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Effect of Agronomic bio fortification of micronutrients on the yield of major cereals

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Abstract
Agronomic bio fortification is the way easier to improve the concentration of micronutrients in the grains of cereals than genetic bio fortification. It involves the soil and foliar application of nutrients. This paper explains the foliar application of the nutrients, which proved to be more effective than soil application in improving the yield components of the crops. This is the quickest method and also a very easier one to increase the micronutrients like iron and zinc in the cereals as the concentration of these nutrients is very less leading to deficiency, mainly in the areas where cereals are taken as the staple food. The main aim of this review is to focus on the agronomic bio fortification with zinc and iron in the cereals like rice and wheat.

Keywords: Agronomic biofortification, cereals, iron, zinc, foliar application, soil application, micronutrients

Introduction
The deficiency of micronutrients is one of the biggest problems around the world. This kind of deficiency is more in the developing countries of Asia and Africa as they consume cereals as a staple food. According to the reports of FAO, 2013 [22] micronutrient deficiency affects more than two million people globally which is due to the inadequate intake of essential micronutrients like zinc, iron, selenium and vitamin A, vitamin C, etc. in the daily diet (White and Broadley, 2009; WHO, 2012) [54, 55], which is also called as hidden hunger. Thus, an increase in the micronutrient concentration in the staple foods is the crucial step that helps in reducing the deficiency and this can be achieved by biofortification (Ram *et al*., 2013) [43].
Biofortification can be done in 2 ways *i.e.* genetic biofortification and agronomic biofortification. Genetic biofortification is also called a plant breeding strategy which includes genetic engineering techniques, this is a more sustainable and cost-effective approach that is used for improving the micronutrient concentration in the cereals but it is a long-term process with significant efforts and resources, apart from this most of the countries are not so interested about genetic engineering techniques. Therefore, a short-term approach is required to improve the micronutrient concentration in cereal grains. Agronomic biofortification is one such approach that involves the application of foliar fertilizers or combined soil and foliar fertilizers which is a highly effective and practical way to maximize the absorption and accumulation of micronutrients in the grains, this can be used instead of genetic biofortification.

1. Agronomic biofortification of rice
Rice is a staple food of nearly two-thirds of the population and played an important role in the Indian economy. It also contains a low nutritional value when compared to other cereals (Babu, 2013) [7]. Being exposed to more processing, most of the nutrients present in the aleurone layer are lost due to the de-husking of the rice grain (Jena *et al*., 2018) [31]. Apart from this, the endosperm of rice is deficient in the majority of nutrients which includes proteins, micronutrients, vitamins etc. Agronomic biofortification which is also called as Ferti-fortification (Prasad, 2009) [42], is an immediate and effective process to increase the accumulation of micronutrients, particularly iron and zinc in cereals.

1.1 Zinc (Zn) Biofortification
Zinc is one of the important micronutrients. On average one-third of the world's population is affected by zinc deficiency (Hotz and Brown, 2004) [29]. Deficiency of zinc leads to various

physiological problems like growth retardation, impaired brain development, decreased physical performance, poor birth outcomes in pregnant women and also increased susceptibility to infectious diseases pneumonia and diarrhoea (Black *et al*., 2008; Gibson, 2012; Krebs *et al*., 2014; Terrin *et al*., 2015) [9, 24, 33, 53]. It is also one of the most important factors limiting the productivity of rice and causes nutritional disorders with adverse impacts on human health worldwide (Zulfiqar *et al*., 2020) [61].

Thus, an increase in the concentration of zinc in rice grain is crucial and it can be done by applying this micronutrient either to soil or foliage. According to Saha *et al*., 2017 [47] application of zinc in soil and foliar form at maximum tailoring and flowering stage resulted in the yield of grains rich in zinc and also an increase in the availability of zinc in cooked rice. Likewise, Shivay *et al*., 2015 [49] observed an increase in the yield attributes with the application of 5 kg Zn ha^{-1} in the form of soil application along with 1 kg Zn ha^{-1} in foliar form. On the other hand, Patil and Meisheri, 2003 [39] found an enhancement in the uptake of zinc content in the straw as well as grain with the application of 25 kg of $ZnSO_4$ ha^{-1} or 10 kg of Zinc chelate ha^{-1}.

Table 1: Effects of various treatments on soil and foliar application of zinc in rice

S. No	Crop	Best treatment	Result	Reference
1.	Rice	Application of 25 kg Zn So_4 ha^{-1} or 10 kg Zinc chelate ha^{-1}	Improvement in the zinc uptake in grain and straw	Patil and Meisheri, 2003 [39]
2.	Brown rice	Foliar application of zinc	Improved zinc concentration in rice	Wissuwa *et al*., 2008 [56]
3.	Rice	Application of 0.2% Zinc sulphate in foliar form followed by 2% Zinc enriched urea application	Higher concentration of zinc in straw and grain	Pooniya and Shivay, 2011 [41]
4.	Rice	Application of 5 kg Zinc ha^{-1} in the form of soil application + 1 kg Zinc ha^{-1} in foliar form	Increase in the grain yield, kernel yield, husk yield, straw yield, biological yield and harvest index.	Shivay *et al*., 2015 [49]
5.	Rice	Zinc application in soil and foliar form at maximum tillering and flowering stage	High Zinc content in grains	Saha *et al*., 2017 [47]
6.	Rice	Foliar zinc application @ 0.5%	Improved growth and yield attributes	Hasim *et al*., 2021 [28]

Foliar application of zinc was better from the point of view of biofortification with zinc to the rice grains. However, most of the zinc which is applied in the form of foliar application was remained in the husk. Generally, foliar application of zinc is carried out at the late stage of the crop, it was not as effective as the application to the soil which affects the characteristics like yield as well as concentration and absorption of N, P, K and Fe in rice. This study showed that proper soil application of zinc sulfate followed by foliar application is the best approach.

Zinc concentration in the grain can be improved and the deficiency of zinc can be corrected with the foliar application of zinc. However, the genotype of rice and the growing conditions have a great impact on the effectiveness the foliar application zinc in the agronomic way to improve the concentration of zinc in the grain. Most of the zinc which is sprayed in the form of foliar fertilizers is absorbed by the epidermis of the leaf, zinc regulating transporter help in the remobilization and transfer of zinc into the grain of rice through the phloem.

Based on previous studies, it is observed that there is a varied effect of foliar zinc spray with different soils. For example, loamy soils have shown high zinc concentration than sandy soils. However, an increase in the grain yield can be seen after foliar application of zinc in zinc-deficient soils.

According to the research done by Phuphong *et al*., 2018 it is found that using zinc enriched seed had no impact on grain yield and concentration of zinc in the next sown crop when compared with non-enriches seeds. Thus, high zinc concentration in the rice grain helps in improving human health and also provides various agronomic benefits like seedling viability and vigour, higher yields and less seed rate required for sowing when grown in soils that are deficient in zinc.

1.2 Iron (Fe) Biofortification

Iron is the most important micro mineral nutrient in humans. Although it is the second most abundant metal in nature and the fourth element in the earth's crust, around 11% of Indian soils are deficient in iron (Singh, 1999) [51]. The deficiency of iron causes various problems which include anaemia, weakness, fatigue, dizziness, drop-in work capacity as well as intellectual performance (Lynch, 2003) [36]. This can be corrected by agronomic biofortification of the micronutrient which involves soil and foliar application of iron. When compared to different inorganic iron carriers $FeSO_4.7H_2O$ is the most commonly used fertilizer to correct the deficiency of iron in rice (Ram *et al*., 2013) [43]

Synthetic iron chelated are generally the most effective sources of iron for soil and foliar application, their cost can be expensive but can be profitable if the plants are of high value (Fageria *et al*., 2002) [20]. Based on the research done by Das, 2000 [16] soil application of 20 kg iron per hectare in the form of $FeSO_4$ showed less results than the application of 2% of un-neutralized $FeSO_4$ in three foliar sprays which is used to correct the iron deficiency in the rice grown in coarse-textured soils.

Table 2: Effects of soil and foliar application of iron in rice

S. No	Crop	Best treatment	Result	Reference
1.	Rice	Application of 2% un-neutralized iron sulphate in three foliar sprays	Used to correct iron deficiency in coarse-textured soils	Das, 2000 [16]
2.	Rice	Foliar application of iron	Increased uptake of iron in grains	Dhaliwal *et al*., 2010 [17]
3.	Rice	Foliar spray of $FeSo_4$ at various growth stages	Improvement in grain yield due to the translocation of iron to economic parts	Singh *et al*.,2013 [50]
4.	Rice	Application of $FeSo_4$. $7H_2O$	Correct iron deficiency in rice	Ram *et al*., 2013 [43]
5.	Rice	Combined foliar application of iron and zinc	Increased intake of Fe and Zn in rice-based food or meals	Zhang *et al*., 2017 [58]
6.	Rice	Foliar application of iron sulphate @ 1.0% at 40, 50, 60, 70 DAT	Highest panicle length, no. of grains per panicle, filled-grains per panicle, 1000 grain weight	Hashim *et al*., 2021 [28]

A significant increase in the iron concentration in grain can be seen with the combined soil and foliar application of iron in rice. Combined soil and foliar application led to absorption of the iron by rice plant continuously for a long time. Thus, iron finally accumulates into the straw and grain. In case of soil application of iron in inorganic form results in conversion of Fe^{-2} to Fe^{-3} leads to unavailability of nutrients in field conditions at high pH (Fernandez and Ebert, 2005) [23]. Most of the research on iron application of iron over the application on soil (Ram *et al*., 2013) [43] as iron can be translocated easily from tip of the plant until the immobilization of iron does not occur.

2. Agronomic biofortification of Wheat:

Wheat is one of the three utmost important cereal crops in the world and is an important source of micronutrients, proteins and calories for the majority of the world's population especially in developing countries (Shewary, 2009) [48], but the products of wheat are generally low in bioavailable iron and zinc which results in the deficiency of these micronutrients in countries where wheat is consumed as a staple food (Balk *et al*., 2019) [8]. In addition, the processing of wheat after harvest significantly reduces the concentration of zinc and other minerals, which further increases zinc deficiency in humans (Cakmak, 2008; Kutman *et al*., 2011; Zhang *et al*., 2010) [15, 34, 59].

2.1 Zinc biofortification

The deficiency of zinc in the wheat-growing soils leads to an inherently low zinc concentration in grain and it is also known as a reason for low human zinc intake (Alloway, 2009) [5]. According to Bybrodi and Malakouti, 2003 [11], when compared to other nutrient deficiencies like iron and copper, wheat is more sensitive to zinc deficiency. Biofortification with zinc fertilizers mainly foliar fertilizers works well for wheat and other cereals as well (Cakamk and Kutman, 2018) [14]. By making use of agronomic methods zinc content of the grain can be increased by fertilizing the plants with zinc salts; for example, foliar application of $ZnSO_4$incraesed the total zinc content of grain by around 60% (Zhang *et al*., 2012) [57]. Thus, zinc application on the soil is less effective in increasing zinc levels in grain, whereas foliar application of zinc leads to a notable increase in grain zinc concentration in wheat (Cakmak *et al*., 2010a; Cakmak *et al*., 2010b) [12,13].

Table 3: Effects of soil and foliar application of zinc in wheat

S. No	Crop	Best treatment	Result	Reference
1.	Wheat	Foliar application of zinc	Increased zinc concentration in grain and flour	Erdal *et al*., 2002 [19], Cakmak *et al*., 2010b [13]
2.	Wheat	Foliar zinc application at the early seed development stage	Increased concentration of zinc in wheat grain	Ozturk *et al*., 2006 [38]
3.	Wheat	Foliar application of Zinc sulphate	Increase in the total zinc content of grain by 60%	Zhang *et al*., 2012 [57]
4.	Wheat	Zinc application in the foliar form	Enhancement in the number of grains per panicle	Karim *et al*., 2012 [32]
5.	Wheat	Alone application of zinc in the foliar form or combined application with soil	Increase in the concentration of zinc in the grain by 84% and 90%	Zhou *et al*.,2012 [60]
6.	Wheat	Foliar application of zinc at early grain filling stage	Increased zinc concentration by 82.9%	Li *et al*.,2014 [35]
7.	Wheat	Foliar application of zinc	Increased concentration of zinc in the grains form 44.4mg kg^{-1} to 52.8 mg kg^{-1}	Hao *et al*.,2021 [27]

To increase the zinc concentration in grain and flour, the foliar application of zinc was much better than the application of zinc to the soil, although much less zinc is applied in the foliar application than in the soil (Cakmak *et al*., 2010b; Erdal *et al*., 2002) [13, [19]]. Li *et al*., 2014 [35] reported that foliar application of zinc in the early stage of grain filling significantly increased the zinc concentration in the grain (by 82.9% compared to the control) and the efficiency of zinc utilization (by 49% compared to the jointing). This may be due to the fact that the zinc which is applied in the form of foliar spray is easily translocated from the vegetative tissues to the grain through the phloem because of its high mobility in the phloem.

The timing of foliar application of zinc is also an important factor that determines the effectiveness of zinc fertilizers applied by foliar application to increase the concentration of zinc in grain. The concentration of zinc in straw during the harvest stage was lower when applied at the early stages, this may be due to the translocation of zinc to the straw during the development of wheat. However, the concentration of zinc in grain did not increase which indicates that there is no re-translocation of zinc into the grain from straw (Li *et al*., 2014) [35].

It is expected that a great increase in zinc concentration in

crops can be achieved when zinc foliar fertilizers are applied to plants at a late stage of growth (Habib, 2009) [25]. Under field conditions the concentration of zinc in the grain is increased, this is due to the highest accumulation of zinc in the grain occurring around the early milk stage. On the other hand, Ozturk *et al*., 2006 [38] found that foliar application of zinc at an early stage of seed development showed the greatest increase in the concentration of zinc in wheat grain in zinc-deficient soils.

2.2 Iron biofortification

The amount of iron needed by cereal crops is extremely low, however, it is essential for healthy growth and life cycle completion of the crop (Rawashdeh and Florin, 2015) [26]. Iron is profusely available in almost every kind of soil and can be taken by the plant through different methods (Rehman *et al*., 2021) [45], Plants growing in soils with restricted accessibility of iron are ineffective to accumulate adequate amounts of iron in their edible parts, resulting in nutrition disorders related to iron deficiency in humans depending upon staple food crops like cereals (Rengel *et al*., 1999, White and Broadley 2009) [46, 54]. However, Agronomic biofortification increasing iron concentration throughout agricultural approaches is a wide applied strategy to reduce the prevalence of iron deficiency in humans (Pfeiffer and McClafferty,2007, Borg *et al*.,2009, Cakmak *et al*., 2010, Aciksoz *et al*.,2014, Naz *et al*.,2015) [12, 40, 10, 1].

Table 4: Effect of soil and foliar application of iron in wheat

S.no	Crop	Best treatment	Result	Reference
1.	Wheat	Foliar application of $FeSO_4.7H_2O$ or iron chelates	Reduction of iron chlorosis	Rehm and Albert, 2006 [44]
2.	Wheat	Foliar application of ferrous sulphate or chelates	Helps in the reduction of iron chlorosis	El-Fouly *et al.*, 2011 [18]
3.	Wheat	Foliar application of iron at 200 to 600 ppm	Increased plant height, spike length, grain yield, thousand grain weight, grain weight per spike and protein yield.	Ali, 2012 [3]
4.	Wheat	Nano iron fertilizer application in the foliar form	Good impact of number of tillers, number of seeds per spike, grain yield, biological yield and 1000 grain weight.	Armin *et al.*, 2014 [6]
5.	Wheat	Foliar application of iron @ 4 kg ha^{-1}	Increased flag area, spike length, leaf area tiller, grains per spike and 1000-grain weight	Ali *et al.*, 2021 [4]
6.	Wheat	Foliar application of iron	Increased iron concentration in the grain from 39.4 mg kg^{-1} to 41.3 mg kg^{-1}	Hao *et al.*, 2021 [27]

El-Fouly *et al*., 2011 [18] observed that the application of ferrous sulfate or chelates as foliar sprays is found to be more productive and efficient than soil application in correcting iron chlorosis in wheat. Similarly, Rehm and Albert, 2006 [44] concluded that foliar spray of $FeSO_4.7H_2O$ or Fe-chelates is found to be more productive and profitable than soil application in plants correcting Fe-chlorosis in wheat plants. Likewise, Ali, 2012 [3] found that the application of iron in the foliar form from 200 ppm to 600 ppm at various stages of growth resulted in increased plant height, 1000-grain weight, spike length, grain yield, grain weight per spike, the protein content of grain and protein yield of wheat plant in two seasons as compared to untreated treatment.

Ali *et al*.,2021 [4], reported that foliar application of iron at the rate of 4 kg ha^{-1} considerably increased the flag leaf area, leaf area tiller, spike length, grains per spike and 1000-grain weight. According to Fageria, 2009 [21], foliar application is more productive and economical when compared to soil application in case of some immobilized nutrients in the soils like iron.

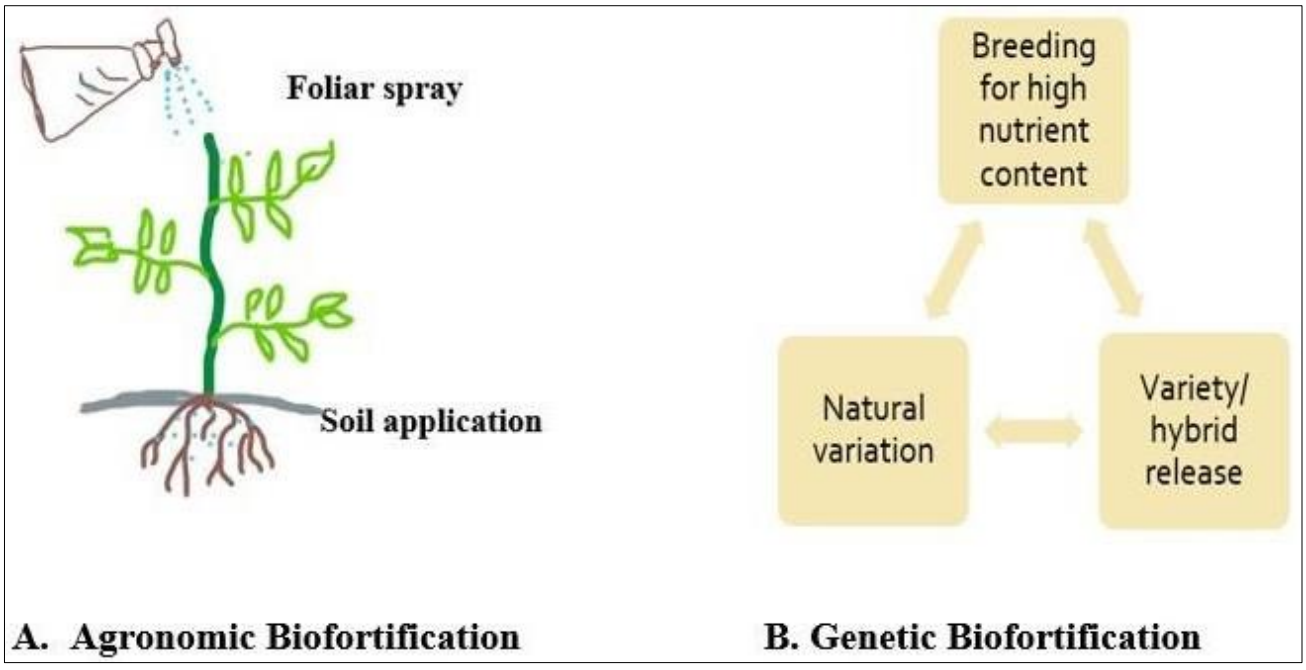

Fig 1: Agronomic vs. Genetic biofortification

Conclusion

As malnutrition is a major problem in the countries where cereals are consumed as the major staple food, agronomic biofortification is a good solution through which micronutrient concentration can be increased in the cereal crops through fertilization, which can be done by applying fertilizers to the soil or foliar application or the combination of both. Among them, foliar application of fertilizers is the most effective one as it helps in absorbing the nutrients more rapidly and effectively than soil application.

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