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Zinc mediated agronomic bio-fortification of wheat and rice for sustaining food and health security: A review

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Abstract
Zinc (Zn) is essential for growth and development of plants, animals and human beings. Its deficiency poses a serious challenge for crop production, especially for wheat and rice, which are considered as staple food crops in most of the developing countries. Beside plants, health related issues in human beings also reported due to deficiency of Zn, which calls for suitable research strategies that can boost the yield and quality of crops, Zn concentration in the grains of cereals such as rice and wheat, increase Zn bio-availability in diets. Across the globe several strategies viz., supplementation, pharmaceutical preparation, food fortification and dietary diversification have been attempted to solve the problem of Zn deficiency induced malnutrition but the agronomic biofortification seems more feasible option particularly in developing countries, where other alternative could prove costly. It could easily be achieved through improved approaches such as integrated nutrient management (INM) and integrated soil fertility management (ISFM) because these helps in enhancing the uptake of micronutrients like Zn, particularly in deficient soils. Though, agronomic biofortification helps to reduce the health hazards still more research efforts are needed to solve the problem of malnutrition and food insecurity for a better and healthy future.

Keywords: Agronomic bio-fortification, Zinc, wheat, rice, food and health security

Introduction

The Zinc (Zn) is recognized as an essential nutrient element for plants and animals during 1920s and 1930s [59, 62]. It is also essential component of more than 300 enzymes [17] involved in synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids as well as in the metabolism of other micronutrients. It plays a central role in the immune system, affecting a number of aspects of cellular and humoral immunity [56] and acts as a catalytic, structural and regulatory cofactor [40].

Zinc deficiency is currently listed as a major risk factor for human health and cause of death globally [8, 52] affecting both crops and human beings [66, 30, 65]. According to World Health Organization (WHO) report [67], zinc deficiency ranks fifth amongst the most important health risk factors in developing countries and eleventh worldwide. About 230 million undernourished people belong to India (> 27% of the world's population) [15]. Zn deficiency in human beings causes impairment in the immune system, learning ability and physical growth and increase in mortality and infections [18], such disorders affects 27% of the total population in India [68], particularly the children's of less than 5 years of age with nearly 4, 50,000 deaths [3].

Globally, rice and wheat is considered as major staple food crops for majority of the population and contributes to two-thirds of the energy needs of humans [48]. In India, rice-wheat cropping system occupies about 10 million ha area mainly in the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal [47]. Adoption of such cropping system led to micronutrient malnutrition [65]. Most prevalent micronutrients deficiencies are iron, iodine, zinc and vitamin A induced malnutrition affecting more than two billion peoples in developing countries [36]. Among cereals, wheat and rice are inherently low in Zn and growing them on potentially Zn deficient soils (around 50% cereal cultivated soils) further reduces the Zn content in grains and diets, crop yields and nutritional quality of crops [11, 25]. Micronutrient deficiencies, particularly Zn, in staple food crops are really a cause for concern to feed the large population with adequate quantity of healthy food.

Thus, efforts have been made to address this malady through various interventions like pharmaceutical preparation, food fortification and dietary diversification but proved unrealistic and unacceptable due to many reasons [23] viz., beyond the reach of large masses in the developing nations due to their high cost [5, 60]. As a consequence bio fortification of staple food crops with higher micronutrients contents through genetic bio-fortification and agronomic bio-fortification gaining prominence now a day. The former involves selection of varieties genetically rich in micronutrients such as zinc while, the later relies on application of appropriate fertilizers to enrich the micronutrients status in the grains. Agronomic bio-fortification has so far been most effective with zinc and selenium [14]. Research results from Turkey showed increased yield and grain zinc concentrations with zinc fertilization of various cereals (maize, sorghum, barley, wheat) and dicotyledonous (soybean, safflower, pea, common bean, canola, common vetch) crops [13, 71] and upto three folds increase in yield and grain Zn concentrations of rice with the application of Zn-enriched urea were reported from the field studies in India [12]. Zn mediated agronomic biofortification of cereals such as wheat and rice proved useful for enriching the micronutrient content in the edible parts and thus overcome hidden hunger caused due Zn micronutrient deficiency to some extent besides rectifying the deficiency in dietary intake. However, it is treated as complementary to breeding (genetic biofortification) approach and considered as a short-term panacea to increase micronutrient availability [24, 64] rather than long term sustainability.

It is high time to join the hands across the globe-developed and developing nations- to address the issue of micronutrient deficiencies occurred in staple food crops such as rice and wheat. Along with food security due attention must be paid to nutritional and healthy food enriched with micronutrients like Zn in adequate amount for the masses whose staple food being the rice and wheat, most of them belongs to developing countries.

Agronomic biofortification

It is an agronomic strategy to increase micronutrient content and bioavailability for human nutrition in the edible parts of crops by adding micronutrient fertilizers to the soil or plant leaves [19, 20]. However, successfulness to enhance micronutrient availability for crop uptake is largely depends on better soil health. It could be achieved through improved strategies like integrated soil fertility management (ISFM) which is defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity [63].

Agronomic bio fortification for improvement in wheat and rice yield

Ananda and Patil[2] observed highest grain yield with combined application Zn and Fe micronutrients (42.23 q ha^{-1}) followed by sole application of Fe @ 25 kg ha^{-1} (40.94 q ha^{-1}) and sole application of Zn @ 25 kg ha (40.74 q ha^{-1}). Significantly higher grain and straw yield were obtained at 20 kg Zn ha^{-1} along with recommended doses of fertilizers [37]. Foliar application of Zn @ 216 g ha^{-1} to wheat crop produced more number of spikes per unit area than no zinc treatment [73]. Wheat grain yield is also significantly influenced under N, Zn and B treatment [34]. Soil and foliar spray of Zn to wheat crop under alkaline soil conditions significantly increase the grain yield as well as 1000 grain weight [38]. High wheat grain yield was also observed under soil application of Zn as well as foliar Zn + propiconazole treatment than no Zn application [49].

Agronomic bio-fortification of rice with zinc is effective in improving the grain as well as straw yield of rice under several studies. Application of $ZnSO_4$ as soil application @ 10 Kg ha^{-1} increase grain as well as straw yield of rice in the tune of 31.9 q ha^{-1} and 68.24 q ha^{-1}, respectively [42]. Zinc application has significant effect on grain as well as straw yield increase [60] as compared to control. Mustafa *et al.* [43] reported that yield and yield attributes of rice was significantly superior due to foliar application of 0.5% Zn solution 15 days after transplanting (21.0 g) over control treatment (18.52 g). Organic matter application increases total Zn content, proportion of readily available form (labile Zn) for plant uptake [53]. Green manure crops (as mulch or soil amendment) are also proved effective to enhance nutrient bioavailability, yields and grain Zn nutritional quality [46]. Combined application of mineral fertilizers and organic matter increase the agronomic efficiency of mineral fertilizers in case of Zn biofortification in rice [21].

Agronomic bio fortification for improvement in wheat and rice quality

Various researchers made significant efforts for quality improvement of wheat grains through bio-fortification with different mineral nutrients, of which application of Zn as a bio-fortification material has significant affects on total carbohydrate and wet gluten content in wheat grain [37]. Zn application was quite effective even under adverse soil conditions (soil alkalinity) in improving the protein content of wheat grains [38]. Protein content in wheat grain was significantly increased under micronutrient treatments[57]. Foliar application of micro elements is also effective in improving the protein content in wheat grains [72]. Application of N, Zn and B significantly affects the Zn concentration in grain as well as straw of wheat crop [34]. Zinc mediated bio-fortification significantly improved quality parameters of rice grain viz., crude protein (5-19%) in rice genotypes[61]. Studies from various countries indicated average Zn concentration in the range of 20 to 35 mg kg^{-1} in whole grain of wheat [51, 10, 54].

Effect on concentration and uptake of Zn and other nutrients in wheat and rice grains

Application of Zn to wheat crop at different doses significantly influenced the total uptake of macro nutrients like N, P, K and micronutrients like Zn, Fe and Mn when applied in soil [1]. Application of Zn along with RDF at higher doses increases the total N, K and Zn uptake[37]. Application of N, Zn and B significantly affected the total Zn uptake by grain and straw of wheat [34]. Soil Zn application increase the Zn concentration in wheat grains by 19% and by 63% through foliar application under various Zn-enriched fertilizers experiments in several African countries [33]. Mc Donald *et al.* [41] found that application of zinc @ 7.6 kg ZnSO4 ha^{-1} significantly increased the concentration of zinc (20 ppm) in wheat grain as compared to control treatment. Similarly, application of zinc increased the concentration of zinc in wheat grains from 45.45 to 67.27 microgram $gram^{-1}$ under pot experiment [50].

Highest Zn concentration in paddy rice with foliar Zn spray @ 0.5% $ZnSO_4$ applied at panicle initiation, booting, 1 and 2 weeks after flowering [4], while foliar application of Zn at early growth stage (panicle initiation and booting) had no effect on seed Zn concentration. Site (soil and foliar) of zinc nutrient application has also significant effect on Zn content in whole rice grain [61]. Soil and foliar zinc application increased Zn concentration in rice by 7% and 25%, respectively [33].

Improvement in bioavailability of Zn for nutritional and human health security

Zn deficiency is related to growth failure, decreased immunity, increased susceptibility to infection, morbidity and mortality[22]. Therefore, Zn bioavailability plays a crucial role in rectifying these odds arose as a consequence of zinc deficiency occurred due to low bioavailability of Zn[23]. It is reported that food with high amounts of phytic acid has low Zn bioavailability [9, 16]. Thus, phytate level is most reliable approach used to measure the Zn bioavailability in human being. Hotz and Gibson[29] suggested to use phytic acid to zinc molar ratios of < 5, 5-15 and >15 for a corresponding Zn bioavailability factor of 55, 35 and 15%, respectively. Gibson[26] in an another study further reported the revised estimates of WHOs categorization of the diets into low, moderate, and high bioavailability based on the Zn bioavailability in the following order i.e.~15%,~30% or 35%, and~50% or 55%. Efforts have been made in India through Zn-enriched urea to improve the Zn bioavailability, rice yields and grain Zn concentrations up to three times[12]. Research indicated Zn fertilization increase Zn bioavailability in humans [31] as well as increase concentration in crops and reduction in phytate concentration level [32].

Constraints and potentials

In low-income countries accessibility and affordability of the fertilizers are two major concerns for resource poor farmers, which favours breeding intervention to improve the crop nutrition status [13, 39]. The other challenges faced by the marginal and small farmers in the effective implementation of agronomic biofortification include limited availability of organic manures and mineral fertilizers, extra labour requirements and costs and environmental stress [27]. Besides, it requires sophisticated infrastructure and hence high costs to improve the Zn concentration in grain cereals like rice and wheat [55, 16]. However, these shortcomings could be addressed through a whole supply chain approach [58]. Agronmic biofortification holds great promise and offers a potential solution for alleviating the Zn induced deficiency *per se* and malnutrition in general. It has greater spatial extent and requires less behavioral change in comparison to other nutrition improving interventions [28]. Therefore, it is more accepted strategy as compare to supplementation and diet diversification [6].

Conclusion

Today, malnutrition and food insecurity are the biggest challenges before the humanity with their vicious presence in the developing countries. These are mostly dominated by the micronutrients led deficiencies occurred in the cereal crops such as rice and wheat, which used to be the staple food grains for satisfying the food needs of majority of the population in these nations. Rice and wheat grains generally lacks in micronutrients particularly zinc causing staple food induced Zn deficiency malnutrition. Such micronutrient deficiencies could be addressed through transgenic or genetic engineering bio-fortification but its success is limited due to genetic variation. This kind of limitations calls for suitable alternatives to overcome the zinc induced malnutrition and undernourished situation. In this context, attempts have been made through several approaches viz., supplementation, pharmaceutical preparation, food fortification and dietary diversification but due to their cost and technological requirements restricts their spatial extent. In such situations, agronomic biofortification strategy seems more feasible option particularly in developing countries, where other alternative could prove costly. It could be a boon in mitigating the malnutrition problem on one hand and supply of healthy food on the other hand besides yield increase and health security in the years to come in many developing as well as developed countries. However, the success of agronomic biofortification largely depends on bioavailability of micronutrients like Zn to human food via soil-plant-human chain, which could effectively be strengthened with the adoption of improved nutrient management approaches such as integrated nutrient management (INM) and integrated soil fertility management (ISFM) to ensure the enhanced uptake of micronutrients particularly in micronutrient deficient soils. Agronomic biofortification of rice and wheat with Zn not only improves the yield and quality of grains but also its bioavailability in diet. Thus, it may prove to be a suitable and sustainable strategy in reducing the health hazards but with more research efforts to solve the problem of malnutrition and food insecurity for a better and healthy future.

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