Review Article

Agronomic biofortification of zinc in wheat

Abstract

Intensive cropping system with imbalance use of fertilizers are responsible for declining soil health, underground water table, declining land and water productivity, emergence of new micronutrient deficiencies, new weed flora, and resistance to herbicides especially in emerging countries. This is further intensified when micronutrients particularly zinc (Zn), which is essential for human health, particularly in developing countries. Zn biofortification is a strategy for improving the intrinsic Zn content of the edible portion of plants via application of Zn-enriched fertilizers to soil or by foliar application at a predetermined stage and a proper dose. The most common cereal in the human diet is wheat, which make it most suitable targets for agronomic biofortification. The concentration of Zn in wheat grain is genotype-dependent and interacts with the environment, causing variation in micronutrient concentrations. Given the central importance to Zn in cereal-based nutrition, zinc biofortification appears as an innovative technology to alleviate the zinc deficiency in human health, especially on the Indian subcontinent, by applying Zn either as a foliar or soil application.

Introduction

Among the cereals, wheat (*Triticum aestivum* L.) is considered as the most important field crop in the world covering 220.10 m ha and with a production of 763.26 m t (USDA, 2019). It is used as staple food by more than one third of the world's population. As one of the commonest cereal crops, it plays an important role in daily energy intake and in many developing nations, provides over 50% of the daily caloric intake (Cakmak, 2008). In India, wheat is the 2nd most important food crop next to rice with a production of 99.87 mt in 29.65m ha in the year 2018-19. The share of wheat to total food grain production in India is around 35% and it occupies about 23.3% of the total area under food grains (MoA&FW, 2019). It is quite clear that sustaining wheat productivity is essential to both food as well as nutritional security in India.

Inappropriate and indiscriminate use of chemical fertilizers along with continuous cultivation of high yielding crop varieties and primary emphasis offered to macronutrients have led to the depletion of native micronutrient in most of the Indian soils (Singh *et al*., 2011). In intensive cropping without balanced fertilization had led to depletion of major as well as micro nutrients from the soil. Now deficiency of zinc has become so widespread that it ranks next to N and P. Studies have reported that about 30% of the cultivated soils worldwide are deficient in zinc (Zn), and about 50% of the soils used for cereal crop production have low Zn availability for plants (Cakmak, 2018). Nearly 50% soils in north India are deficient in Zn and likely to respond to its application.

Zinc is a vital micronutrient for plants, humans and animals. In plants, Zn is of vital importance for healthy root structure, enzyme activation, detoxification of free radicals and retaining tolerance to plant stressors (Peck & Mc Donald 2010). Zinc exerts a great influence on basic plant life processes, such as (i) nitrogen uptake, metabolism and protein quality; (ii) chlorophyll synthesis, carbon anhydrase activity and photosynthesis (Potarzycki and Grzebisz, 2009). The integrity of cellular membranes also requires Zn to preserve the structural orientation of macromolecules and keep ion transport system (Kumawat *et al*., 2019). Zn has been found useful in improving yield and yield components of wheat. Application of Zn fertilizer either to the soil or as foliar application is one of the effective and productive ways to improve cereal grains (Jiang *et al*., 2008). The increase of cereals and cash crops in modern cropping systems have resulted in a dramatic reduction in food diversity and micronutrient intake. Farmers chose to grow more profitable, highly productive cereal crops, leading to a decline in the area under protein and micronutrient rich legumes. This tendency is evident in a proportional decrease in cereal prices and an increase in price for legumes, fruits, vegetables, and animal and fish protein. Cereals are intrinsically deficient in micronutrients especially in iron (Fe) and zinc (Zn) that subsequently decrease during processing. Low dietary intake of mineral nutrients due to consumption of edible portion of cereals raised on micronutrient deficient soil contributed significantly to “hidden hunger” or malnutrition. It is estimated that nearly half of the world population is affected from Zn deficiency because of low dietary intake of Zn. India alone accounts for a quarter of all under-nourished people globally. Zn deficiency in humans causes a wide range of health complications, including impairment in the immune system, learning ability and physical growth, and increase in mortality and infections.

In India, Zn availability in wheat cultivars varies from 20 to 30 ppm (Shukla *et al*., 2014). Deficiency of Zn in major wheat growing areas leads to poor growth and yield attributes of wheat as well as low Zn concentration in grain and this is considered to be a major factor for low human Zn intake (Aref, 2011). So, there is an urgent need to fortify the wheat grain with Zn because a large proportion of dietary calorie intake of these nutrients is derived from wheat (Bhatt *et al.,* 2020). NPK fertilization in India, which increases cereal crop yields, has often led to decline in concentration of micronutrients particularly at higher rate of application probably by a dilution effect. Balanced fertilization results in the supply of nutrients in a well-balanced ratio, leading to their efficient utilization (Singh *et al.*, 2017). High fertilizer responsive varieties express their full yield potential when trace elements are applied along with NPK fertilizers (Nataraja *et al.,* 2010). Fertilization management strategy could be a rapid solution in this regard. Several studies have revealed that zinc fertilization not only increases yield but also increases zinc concentration in grains (Torun *et al*., 2001).

Effect of agronomic biofortification with zinc

Effect of agronomic biofortification with zinc on growth parameters

In wheat crop with four levels of zinc including control (no Zn), 5 mg Zn, 10 mg Zn, and 10 mg Zn kg^{-1} soil with urea, Nautiyal *et al*. (2011) observed higher plant height and total dry weight with the supply of zinc added at 10 mg kg^{-1} over the control. Gopal & Nautiyal (2012) while conducting a pot experiment reported that growth of wheat plants was improved by applications of Zn (20 mg Zn kg^{-1}) with two foliar sprays of zinc sulfate ($ZnSO_4$) @ 0.5% as compared to only Zn (20 mg Zn kg^{-1}) and control. Nadim *et al*. (2012) performed a field experiment to study the growth and yield responses of wheat to different micronutrients and their application methods. They noticed a higher leaf area index and crop growth rate with the application of zinc @ 10 kg ha^{-1}. Jan *et al*. (2013) during a field trial in the winter season of 2006–2007 observed that maximum plant height has resulted with the soil application of 15 kg Zn ha^{-1} over control plots. At Pantnagar carried out a pot culture experiment to examine the individual and interactive effects of zinc and boron on growth, and yield in wheat (var. HD 2285). Results revealed that plant height and total dry matter content were increased with the application of zinc sulfate at 10 mg Zn kg^{-1} soil (Singh *et al*., 2014). In a soil- pot trial to examine the individual and interactive effects of zinc and boron on growth of wheat (var. HD 2285). They reported wheat crop fertilized with increasing zinc levels significantly increased the plant height and total dry-matter yield over other treatments (Singh *et al*., 2015). Arafat *et al*. (2016) found markedly highest plant height (101 cm) with soil application of Zinc (10.5 kg ha^{-1}) and similarly higher plant height (100 cm) was noticed with side dressing method of zinc application in wheat. Bhutto *et al*. (2016) conducted a study to examine the effect of foliar fertilization of zinc on the growth and yield response of wheat. They observed significantly higher plant height (66.1 cm) and tillers m^{-2} (296.0) with increasing foliar zinc concentration of 2.0% over lower treatments. Chaudhary *et al* (2016) performed a field experiment at Kanpur to examine four levels of Zinc (0, 5, 10 and 15 $kgha^{-1}$) on wheat. They concluded that significantly higher LAI and chlorophyll intensity was with the application of 10 kg Zn ha^{-1}.

At Pantnagar, Srivastava *et al*. (2016) while studying zinc application methods on apparent utilization efficiency of zinc and K fertilizers under rice-wheat rotation concluded that plant height was increased significantly by 5.4 percent with the application of 2 kg Zn ha^{-1} as foliar application compared to control. However, soil application of 5 kg Zn ha^{-1} increased the total number of tillers by 9.7 percent over control. Afzal *et al* (2017) while evaluating different methods of zinc application (control, zinc application in soil before planting 23 $kgha^{-1}$, zinc foliar application, 4% $ZnSO_4$ solution at two stages) reported that maximum plant height at maturity and total number of tillers were recorded in treatment where zinc was applied both in the soil and by foliar application. Barut *et al*. (2017) carried out an experiment to assess the effect of zinc treatments on the growth and yield of three wheat cultivars. They found a significant impact of soil treatments on grain zinc concentrations as the concentration increased from 25.1 mg kg^{-1} (control) to 29.4 mg kg^{-1} (10 kg $Znha^{-1}$). However, the further increments did not show any significant increase. Ali *et al*. (2019) while studying the effect of zinc on the productivity of wheat and soil fertility noticed that application of 10 kg Zn ha^{-1} resulted in higher plant height (85.5 cm) over control (82 cm).

Effect of agronomic biofortification with zinc on yield attributes and yield

A pot experiment conducted by Nautiyal *et al*. (2011) at Lucknow to study four levels of zinc including control (no Zn), 5 mg Zn, 10 mg Zn, and 10 mg Zn kg^{-1} soil with urea in wheat. They observed increasing size of ears, number of $grainsear^{-1}$, seed yield, seed Zn, and starch contents with higher zinc additions over the control. By increasing soil application of zinc from 0 kg ha^{-1} to 50 kg ha^{-1} increased the grain yield by 23% and 21% in the consecutive two years, respectively (Cakmak *et al*., 2010). Hussain *et al*. (2012) while conducting an experiment to study different zinc applications to soil (0, 4.5 or 9 mg Zn kg^{-1}), seed (100 mL of either 0 or 6.75 % Zn w/v sprayed on 1 kg seed) and foliage (distilled-water-sprayed control, 1 mL of 0.05 % Zn w/v at jointing, 2 × 1 mL of 0.50 % Zn w/v at heading or combined jointing and heading sprays) reported an increased grain yield (29 %) with soil application of zinc as compared to other application methods. Morshedi & Farahbakhsh (2012) evaluating the response of three Zn levels (0, 20, 40 kg ha^{-1}) reported that yield components and grain yield of the wheat genotypes increased linearly with increasing dose of Zn × K. Zou *et al*. (2012) carried out an experiment in 23 different experimental sites with four Zn treatments: nil Zn, soil Zn application, foliar Zn application and soil + foliar Zn application for biofortification of wheat with Zinc. They observed 5 % increase in grain yield with soil Zn application over other. Zoz *et al.* (2012) examined response of wheat to foliar application of zinc observed that number of spikes per m^{-2} in wheat increased by 26% with foliar application of 216g Zn ha^{-1} over control. Jan *et al*. (2013) while evaluating the effect of zinc on yield of wheat during a field trial in winter 2006–2007 concluded that markedly higher grains per spike, grain yield, straw yield, biological yield and harvest index were observed in plot receiving 15 kg Zn ha^{-1} over control. Abdoli *et al*. (2014) conducted a field experiment during 2013 and 2014 reported that foliar application of Zn at stemming and grain filling stages was much more effective on grain yield than foliar Zn application at the stem elongation stage.

In Bichpuri, Agra, Chauhan *et al.* (2014) studied the effects of Zn (0, 2.5, 5.0 and 10 $kgha^{-1}$) on wheat in respect of yield, quality and uptake of nutrients. Results revealed application of Zn up to 5 kg ha^{-1} increased the grain and straw yield by 9.7 and 11.5% over the control, respectively. Singh *et al*. (2014) at Pantnagar carried out a pot culture experiment to examine the individual and interactive effects of zinc and boron on the yield of wheat (var. HD 2285). They reported that the increase in the ear length of wheat was 16.4 to 20.0% greater with Zn application of 5 or 10 mg kg^{-1} soil over the control. They also observed an increase in the total grain weight, and 100-grain weight was with Zn application of 10 mg kg^{-1} soil among all. At Pantnagar, Srivastava *et al*. (2014) carried out a field trial and observed the highest pooled grain yields of wheat with soil application of 17.5 kg P ha^{-1} and foliar applications of 2 kg Zn ha^{-1}. Debnath *et al*. (2015) while conducting an experiment on wheat reported the highest grain yield of 5.43 t ha^{-1} with the application of 60 kg P_2O_5 and 5 kg Zn ha^{-1}. They also observed agronomic efficiency for Zn from 56.4 to 83 kg grain kg^{-1}. Arshad *et al*. (2016) performed an experiment to study the effect of zinc levels (0, 5, 10 and 15 $kgha^{-1}$) on the yield of wheat concluded that 10 kg Zn ha^{-1} had resulted in significantly higher wheat spike length, 1000 grains weight, total dry matter, and grain yield. However, highest straw yield was observed with application of 5 kg Zn ha^{-1}. Bhutto *et al*. (2016) conducted a field experiment to examine the effect of foliar fertilization of zinc on the growth and yield response of wheat. They observed significantly higher spike length (9.2 cm), number of grains $spike^{-1}$ (46.4), seed index (51.0, g) and grain yield (5540.7 kg ha^{-1}) with a higher foliar zinc concentration of 2.0% followed by lower treatments.

At Kanpur, Chaudhary *et al.* (2016) performed a study to examine four levels of Zinc (0, 5, 10 and 15 $kgha^{-1}$) on yield and yield attributing characters of wheat. They concluded significantly highest seed yield, number of $tillerm^{-2}$, test weight, with the application of 10 kg Zn ha^{-1}. Gomez-Coronado *et al.* (2016) conducted a field experiment with ten advanced breeding lines and three commercial varieties of wheat along with four zinc application methods and observed that zinc application, especially soil Zn application, resulted in a significant increased to about 10 % in grain yield in all the studied years and cultivars. A greenhouse experiment conducted by Keshavarz & Saadat (2016) on wheat concluded that application of 10 mg kg^{-1} Zn increased the dry weight by 25% (straw) and 32% (grain) in wheat variety ‘Falat’ over control. Srivastava *et al*. (2016) at Pantnagar carried out a field experiment to study zinc application methods on apparent utilization efficiency of zinc and K fertilizers under rice-wheat rotation.

Results revealed the highest mean grain yield with an application of 24.9 kg Kha^{-1} and foliar spray of 2 kg Zn ha^{-1}. Srivastava *et al*. (2016) while conducting an experiment on wheat observed that soil application of Zn was more effective than foliar application of Zn in increasing test-weight. However, for yields foliar application @ 2 kg Zn ha^{-1} increased the of wheat grain yield by 9.5 percent over control. Afzal *et al* (2017) while evaluating different methods of zinc application (control, zinc application in soil before planting 23 kg·ha^{-1}, zinc foliar application, 4% $ZnSO_4$ solution at two stages) reported that spike length, number of spikelets spike^{-1}, number of grains spike^{-1}, 1000-grain weight, biological yield, grain yield and harvest index were recorded in treatment where zinc was applied both in the soil before planting and by foliar application.

A study was performed by Barut *et al*. (2017) to study different Zinc application methods via soil application (0, 5, 10, 20, 30 and 40 kg Zn ha^{-1}) and foliage (0.4% $ZnSO_4.7H_2O$) as foliar spray. The found the highest grain yield with soil application of 20 kg Zn ha^{-1}, yield increment was 27.5% over control. They also reported that soil Zn application increased thousand grain weight significantly (1%) and recorded highest with 5 kg ha^{-1} Zn, but further increments did not have significant effects. A field experiment conducted by Ghasal *et al*. (2017) at New Delhi during 2013–14 and 2014–15 reported that the grain yields, grain Zn concentration and recovery efficiency (RE) was highest with application of 1.25 kg Zn–EDTA + 0.5% foliar spray at maximum tillering and booting stages. Singh *et al.* (2017) while conducting an agronomical trial in Agra during *rabi* seasons of 2010 -11 and 2011-12 reported that mean yield difference of 0.41 t ha^{-1} between 150% NPK and 150% NPK + S+ Zn was observed due to inclusion of S and Zn in treatment. Chowdhury *et al*. (2018) working on late sown wheat reported that maximum spike length (7.28 cm), number of spikelets spike^{-1} (11.27), number of grains per spike (23.85), 1000-grain weight (33.43 g) and number of florets spike^{-1} (33.39) and finally highest grain yield (1.60 t ha^{-1}) was observed with application of 6 kg ha^{-1} Zn. At Ranchi, Firdous *et al.* (2018) while conducting a field trial during 2012-13 and 2013- 14 revealed a significantly increase grain yield (pooled data) and straw yield with soil zinc application of 5 kg Zn ha^{-1} + 2 foliar sprays @0.5% of $ZnSO_4$. H_2O over the control and 5 kg zinc ha^{-1}. However, in case of straw yield it remained at par with 10 kg Zn ha^{-1}. An experiment was conducted by Tao *et al*. (2018) with four levels of zinc (0, 15, 30 and 45 mg Zn kg^{-1} soil) on two wheat cultivars with different gluten levels. They foundthat15 mg Zn kg^{-1}in soil had the strongest effect on grain yield and quality as compared to other. Ali *et al*. (2019) conducted a field experiment to study effect of zinc on the productivity of wheat and soil fertility. Results revealed that application of 10 kg Zn ha^{-1} resulted significantly higher biological yield (6607 kg ha^{-1}) and grain yield (2657 kg ha^{-1}), over control (4283 kg ha^{-1}) and (1923 kg ha^{-1}) respectively. At New Delhi, Kumar *et al*. (2019) carried out an experiment during 2009-10 and 2010-11. They concluded that application of 25 kg $ZnSO_4$ ha^{-1} significantly increased effective tiller m^{-2}, grains $spike^{-1}$, 1000 grain weight, and grain diameter, also the highest straw and biological yields.

Effect of agronomic biofortification with zinc on nutrient content and uptake

An experiment conducted on wheat (cv. Shafaq-2006), Hussain *et al*. (2012) reported that an increased whole-grain Zn concentration (95 %) and whole-grain estimated Zn bioavailability (74 %) was observed with soil Zn application as compared to other application methods. Cakmak *et al*. (2010) showed that increasing foliar Zn application increased grain Zn concentration from 11 mg kg^{-1} to 22 mg kg^{-1} however a combined application of $ZnSO_4$ to soil and foliar spray resulted in a higher Zn content of 27 mg kg^{-1}. Nautiyal *et al*. (2011) at Lucknow conducted a pot experiment in wheat (*Triticum aestivum* L. CV. SP 343) with four levels of zinc including control (no Zn, 5 mg Zn, 10 mg Zn, and 10 mg Zn kg^{-1} soil with urea). They observed increasing grain Zn contents with 10 mg Zn kg^{-1} additions over the control. Kutman *et al*. (2011) noticed an increased whole grain Zn concentration by up to 50% and the endosperm Zn content by over 80% with enhanced N application. Zou *et al*. (2012) carried out an experiment in 23 different experimental sites with four Zn treatments: nil Zn, soil Zn application, foliar Zn application and soil + foliar Zn application for biofortification of wheat with Zinc. They observed a grain Zn concentration of 48 and 49 mg kg^{-1} with foliar Zn application alone or in combination with soil application which significantly much higher than control. Bharti *et al.* (2013) conducted field experiments at Pantnagar and observed that increasing levels of the micronutrient with 20 kg $ZnSO_4ha^{-1}$ + foliar spray (Zn_{20} + F), resulted in 80% increase in grain Zn content.

In Bichpuri, Agra, Chauhan *et al.* (2014) studied the effects of Zn (0, 2.5, 5.0 and 10 $kgha^{-1}$) on wheat. They observed removal of Zn by grain and straw increased from 152.8 to 202.5 and 129.5 to 182.5 gha^{-1} with the increase in Zn levels. The removal of N, P and K increased up to 5 kg Zn ha^{-1}. Kumar *et al.* (2016) at New Delhi, carried out an experiment during the winter seasons of 2013–14 and 2014–15 reported that total N, K and Zn uptake was increased with application of Zn compared to control under 1.45 mg kg^{-1} soil available Zn. Srivastava *et al*. (2016) at Pantnagar carried out a field experiment to study different zinc application methods on apparent utilization efficiency of zinc and K fertilizers under rice-wheat rotation. They concluded that soil application of 5 kg Zn ha^{-1} and 2 kg Zn ha^{-1} as foliar spray increased Zn concentration in wheat grain significantly by 8.0 and 13.5 percent, respectively, over control. Barut *et al*. (2017) concluded that effect of soil Zn treatments on grain zinc concentrations were significant as the concentration in grain increased from 25.1 mg kg^{-1} in control to 29.4 mg kg^{-1} with application of 10 kg $Znha^{-1}$. Afzal *et al.* (2017) while evaluating different methods of zinc application (control, zinc application in soil before planting 23 $kgha^{-1}$, zinc foliar application, 4% $ZnSO_4$ solution at two stages) reported that grain zinc contents (33.11 $mgkg^{-1}$), grain protein contents (10.1%) were observed in the treatment where zinc was applied both in the soil before planting and by foliar application on later growth stages, which is better than all other treatments. Ghasal *et al*. (2017) conducted field experiments during 2013–14 and 2014–15 at New Delhi. Results revealed that grain Zn concentration was highest with application of 1.25 kg Zn–EDTA + 0.5% foliar spray at maximum tillering and booting stages. Jarallah and Amedy (2017) performed an experiment to study the effect of N and Zn use efficiency on nutrients uptake by wheat, observed that the added zinc levels had a significant effect on nitrogen uptake by straw and grain. Increasing added zinc levels of 10, 20, 30 and 40 kg ha^{-1} led to increasing nitrogen uptake by straw of 16.0, 33.5, 26.8 and 26.7%, and by grain of 17.1, 43.4, 37.3 and 31.7%, respectively, compared with the control. Jat *et al.* (2018) conducted a trial during *rabi* seasons of 2009-10 and 2010-11 at Bikaner. They concluded that N, K and Zn content and uptake in grain and straw by wheat significantly enhanced with application of zinc at 3 kg ha^{-1} over control while zinc uptake in grain and straw was significantly increased up to 6 kg Zn ha^{-1} during both the years and also in pooled analysis. Ali *et al*. (2019) conducted a field experiment to study the effect of zinc on the productivity of wheat and soil fertility. They observed utilization of 10 kg Zn ha^{-1} resulted in higher soil N (0.37%), soil P (2.9 $mgkg^{-1}$), soil K (77.6 $mgkg^{-1}$) and soil organic matter content (0.5%) over control.

Conclusion:

Zinc-biofortification of crops either by soil or by the foliar method is required in the present era of intensive agriculture. Mineral fertilizers both macro and micro combined with proper soil fertilization approaches with an increased ability to improve the growth, productivity and nutrient concentration especially zinc in grains, are advocated. Biofortified crops will have a great demand if their beneficial aspects to human health are demonstrated to consumers. Furthermore, there is a need to revise our old formulated fertilizer recommendations keeping in view the present trends of micronutrient deficiencies more particularly of Zn for the overall improvement.

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