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Effect of Foliar Application of Zinc on Zn-fortification and Morph-Physiological Responses of Rainfed Wheat Yield: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Wheat is a staple food in Pakistan and plays a vital role in the country's agriculture. It is one of the country's most widely cultivated and consumed crops, providing millions of people's food and livelihoods. The study reviewed the literature on the effect of foliar application of zinc on zinc-fortification and the yield of wheat grown under rainfed conditions. The review analyzed a range of

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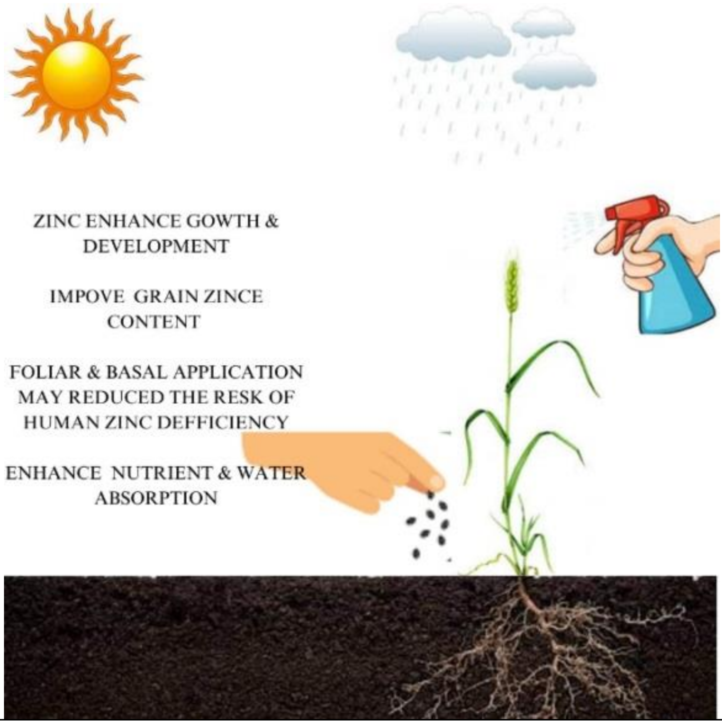
studies that investigated the impact of the foliar application of zinc on wheat growth and grain quality. The results showed that foliar application of zinc significantly improves the zinc content of the wheat grain, which has important implications for addressing zinc deficiency in areas where it is prevalent. Additionally, the review revealed that zinc treatment leads to a noticeable increase in wheat yield, demonstrating its potential to improve agricultural productivity in rainfed farming systems. The review concludes by highlighting the need for further research to optimize the application rate and timing of foliar zinc application to maximize its benefits for wheat production under rainfed conditions.

GRAPHICAL ABSTRACT



Keywords: Zinc; foliar application; rainfed; wheat; grain quality; yield.

1. INTRODUCTION

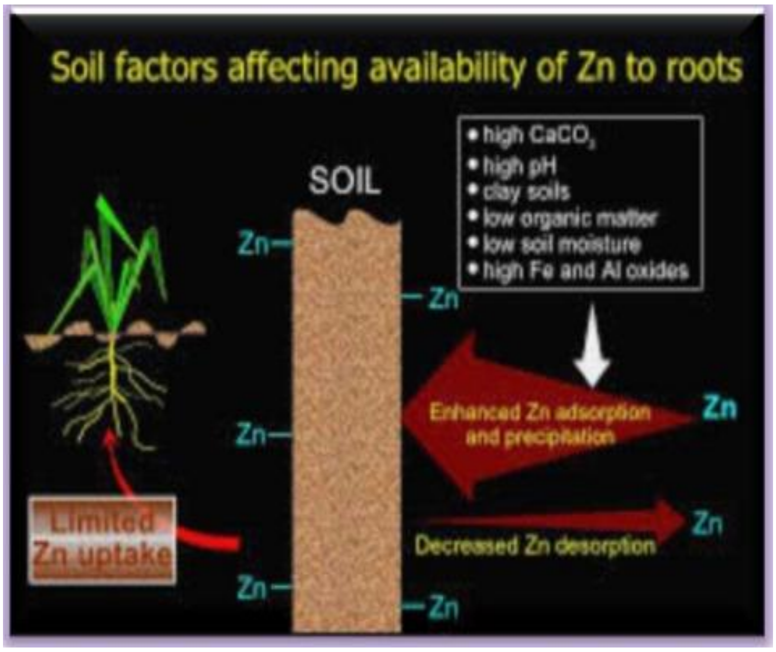
Zinc is an important micronutrient for animals, human beings, as well as plants. Zn is significant element of different enzyme catalyzing many metabolic reactions in plants [1]. Furthermore, zinc is important for photosynthesis, protein synthesis, cell membrane integrity, pollen development, disease resistance, and boosting antioxidant enzymes and chlorophyll levels in plant tissues [2]. Zn produces heat resistance in water-stress plants [3] because the cell membrane is first affected by water stress and is a main part of the plant, therefore, its maintenance is necessary during water stress [4]. Stomata play major role in regulation of temperature during water stress condition [5] and Zinc play important role in the regulation of stomata in water stress condition [4].

Zinc is a vital nutrient that plays a key role in human health, and is the 5th leading cause of illness and death in developing-country populations [17]. At the cellular level, it plays a major role in apoptosis and differentiation [6]. Zinc is required for different functions including taste, respiration, DNA metabolism, vision, and behavior in the human body [7]. It is important for growth and development, particularly in children and pregnant women [10]. It is involved in numerous metabolic processes, including DNA synthesis, cell division, and protein metabolism [8]. Zinc also helps to maintain a strong immune system and promotes skin, eye, and reproductive health [9]. Good food sources of zinc include meat, seafood, dairy products, and whole grains [11] and its deficiency is estimated to affect approximately 2 billion people worldwide [12] and in Pakistan, 37% of the population affected by zinc deficiency [13]. Zinc deficiency is caused by a lack of zinc-rich foods in the diet, poor zinc absorption, and increased requirements during growth and illness [14]. Zinc deficiency adversely impacts immune function, slows wound healing, and inhibits taste and smell [15]. Supplements are available for people who do not get enough zinc from their diet [16].

Cereals are an important part of a balanced diet and provide numerous health benefits [46]. According to the Food and Agriculture Organization (FAO) of the United Nations, cereals account for over 50% of the total calorie intake for almost half of the world's population (FAO. 2022). Cereals are also a good source of carbohydrates, which provide the body with energy and are also rich in fiber, vitamins, and minerals such as iron and zinc [47].

Wheat is one of the most important cereal crops in the world, providing a significant source of food for both humans and livestock [32]. It is a staple food in many countries, and is a critical component of the diets of billions of people around the world, providing essential nutrients such as carbohydrates, proteins, vitamins, and minerals [70]. According to the United Nations Food and Agriculture Organization (FAO), Wheat is one of the most widely cultivated crops in the world, grown on over 220 million hectares with a global production of over 740 million metric tons in 2021, and Pakistan is one of the world's largest wheat producers, with a production of around 25 million metric tonnes in 2021 [18]. In Pakistan, approximately 75% of the cultivated area is irrigated, with the remaining 3.99 M ha being rainfed. Wheat is grown on 8.797 million hectares, with an annual production of 25.07 million tonnes [19].

Pakistan's rainfed areas are essential to the country's agriculture and economy because they provide a major source of food production, including wheat [20]. Rainfed area contributes only about 12% of the total wheat production of the country [21]. Drought is a major issue that has a significant impact on Pakistan's rainfed wheat yield [22]. Over the past three decades, heat waves on agricultural lands have increased, which has an impact on crop productivity worldwide [31]. Mostly the grain-filling stage of wheat results in grain shrink that automatically affect the yield of wheat [23]. A lack of rainfall can also cause soil moisture stress, which can limit crop nutrient absorption and reduce overall yield [24]. Furthermore, drought can increase the risk of plant diseases and pest outbreaks, which can reduce crop yield [25]. Water stress crop losses can have serious consequences for the country's food security and economy [26]. Foliar zinc application can be an effective way to mitigate the effects of drought stress in crops by providing essential micronutrients and improving plant tolerance to stress conditions [27].



Picture 1. Soil Factors affecting the availability of zinc to roots

This picture is taken from a study by Rudani et al. [1] . This picture shows the factors like high $CaCo_3$, high pH, Clay particles, low organic matter, low soil moisture, and high Al oxide that affect the zinc level in soil and retard the availability of zinc to the plant roots.

Wheat crops grown in the field at a global scale have grain Zn ranges from 20.4 to 30.5 mg/kg and the human requirement for good health is 40 mg/kg which shows a solid gap. Foliar application of zinc can provide an effective and efficient method of delivering this essential micronutrient directly to the leaves of the plant. This method allows the plant to absorb the zinc quickly and directly, without having to rely on the slower process of soil uptake. As a result, foliar application of zinc can help to overcome soil-related zinc deficiencies and alleviate the effects of drought stress on crops.

2. ISSUES

2.1 Zinc in Soil

Zinc levels are low in a variety of soils. Soils with high pH, sandy soils, calcareous soils, and soils derived from highly weathered parent materials all have low total Zn levels [63]. Similarly, due to saline soils, vertisol, and highly weathered soils have low plant-available zinc [60]. Zinc soil deficiency is a very common issue at the global level [62]. The Zn soil deficiency has been reported in 57% of the soil samples of Iraq, 35% of Turkey, and 20% of Pakistan [64]. Almost 30% of agricultural soils show zinc deficiency in the World, and in Asia, 30% of soils are zinc deficient [65,66]. Low zinc in soils mostly affects main crops like wheat, oat, sorghum, and maize [64].

Table 1. List of sensitive crop species to zinc deficiency

High	Medium	Low
Bean	Barley	Alfalfa
Citrus	Cotton	Carrot
Flax	Lettuce	Clover
Fruit trees	Potato	Grass
Grape	Soybean	Oat
Corn	Tomato	Pea
Rice	Sugar Beet	Rye
Sorghum		Wheat

Martens and Westermann (1991)

Globally, Zn-deficient soils identified in mostly arid and semi-arid areas of Pakistan and India, and in China, turkey and Australia due to low organic soils [67].

2.2 Effect of Low Zinc on Plant Growth

Low zinc availability in soil has a negative impact on plant growth and development its deficiency stress becomes more sensitive to Zn deficiency stress became more distinct when plants in drought-stressed [50]. For example, a study by Suganya et al.[28] found that zinc deficiency in soil reduced the growth and biomass production of corn plants. Similarly, a study of Rehman et al. [29] reported that a low zinc supply decreased the growth and grain yield of rice plants. The study of Mousavi et al. [30] reported that Zinc deficiency reduces plant growth by impairing the plant's ability to absorb and use essential nutrients like nitrogen and phosphorus, as well as by altering its hormone balance. The study by Rahman et al. [33] reported that low zinc availability in soil reduces wheat growth and if wheat grows in supra optimal temperature. These findings highlight the importance of adequate zinc supply for optimal plant growth and productivity.

2.3 Low Zinc Effect on Plant Height

A deficiency of zinc can significantly impact plant growth and development, including plant height [34]. Several studies have demonstrated the negative effect of zinc deficiency on plant height. For instance, a study by Raj and Nadarajah [35] reported that zinc-deficient maize plants exhibited a significant reduction in plant height compared to plants grown under an adequate zinc supply. Similarly, a study by Gonzalez-Caballo et al. [36] showed that zinc-deficient wheat plants had shorter stems and reduced shoot length compared to plants grown under an adequate zinc supply. The negative impact of zinc deficiency on plant height is attributed to its role in the production of auxins, which are plant hormones that regulate cell division and elongation. Zinc is required for the activity of enzymes involved in auxin biosynthesis and transport [37]. Zinc deficiency leads to a decrease in the production of auxins, which subsequently reduces stem elongation and plant height [38].

2.4 Effect of Low Zinc on Leaf Area Index

The study showed that rice crops grown under zinc-deficient soil significantly reduced growth in terms of Leaf Area Index, Leaf Area Duration, Crop Growth Rate, Total Dry Matter accumulation, and Net Assimilation Rate [39]. The study of Hafeez et al. [44] resulted that zinc deficiency shows a negative effect on plant growth by decreasing the number of tillers, small leaf area, and by increasing the crop maturity period. Moreover, a recent study by Ahmad et al. [48] investigated the effect of different zinc concentrations on the growth and development of rainfed wheat. The study found that low zinc concentrations resulted in reduced leaf area and stunted growth.

2.5 Effect of Low Zinc on Relative Water Contents

Rainfed agriculture relies on rainfall for water supply, but it is often erratic and unreliable, leading to water stress in plants [71]. Low levels of zinc in the soil reduce the plant's ability to produce ABA, leading to inefficient stomatal closure and increased water loss. This can lead to wilting, stunted growth, and reduced yield [72]. The study of Kumar et al. [40] showed that low zinc in soil decreases water potential and relative water contents also have fewer chloroplast pigments and high tissue Mn concentration. Vazin. [75] found that zinc spray significantly increased the thousand-grain weight of maize under water stress, improving the effects of drought stress. This suggests that zinc spray can be used to reduce the effects of drought stress.

2.6 Effect of Zinc Deficiency on Crop Yield

Zn is mainly a plant micronutrient that is involved in several physiological functions and insufficient supply reduces crop yields in calcareous soil, sandy soils, and soils with high phosphorus conditions [42,44]. The study by Hassan et al. [45] demonstrated the number of tillers, chlorophyll contents, plant growth, and crop yield affected by zinc deficiency. Similarly, the growth and yield of crops are reduced by different abiotic stresses as well as water stress in rainfed areas during the booting, heading and flowering stages [3]. It is also resulted the skipping of irrigation at the grain-filling stage causing a reduction in yield. It is concluded that zinc-deficient plants showed leaf chlorosis, necrosis bronzing, resetting dwarf, and stunting of plants. However, 40% yield was reduced by zinc-deficient soil without the existence of diverse symptoms in plant leaves [49,50].

2.7 Effect of Zinc Deficiency on Human Health

The study of Plum et al. [41] Proved that the Zinc deficiency disturb the normal health of the human like neural development, growth and immunity and in severe cases its consequences are more lethal. The study of Gibson. [43] resulted that the competence of the immune system, risk of stunting, childhood mortality, diarrhea, respiratory diseases, and abortions caused by zinc deficiency.

2.8 Zinc Essentiality for Human

Zinc was discovered to be essential in humans in 1963 [55,56]. Zinc is required to properly operate thousands of transcriptions [57]. Zinc is a second messenger of immune cells, and intracellular free zinc participates in signaling events in these cells [58]. Zinc deficiency in pregnant women during growth periods shows no proper growth. The gastrointestinal, central nervous, skeletal, and reproductive systems are the organs affected by zinc deficiency [61]. Nutritious necessities during lactation are greater than during pregnancy [59].

3. POSSIBLE SOLUTIONS

3.1 Plant Height Increased by Foliar Zinc

The study of Abdoli et al. [51] Revealed that the height of wheat crops significantly increased by foliar application of zinc sulfate at development and grain filling stages however non-significant on the harvest index. A study by Gul et al. [72] revealed that the foliar application of nitrogen, potassium, and Zn at the rate of 0.5% applied two times significantly increases the number of tillers, and gets maximum plant height (100.50cm). The study of Ali et al. [73] concluded that the combined foliar application of Boron and Zinc on the summer tomato significantly increases the growth rate, plant height, leaf area number of branches, and overall growth and yield of the summer tomato.

3.2 Crop Yield Increase by Foliar Zinc

The study of Sattar et al. [52] on the wheat crop grown under different water stress conditions resulted that foliar zinc of 15 mM reduce the water stress impact also increasing the grain yield by increasing the number of grains per spike, grain weight, and biological yield. The study by Noreen & Kamran [53] resulted that foliar application of 4 and 6 mM of zinc significantly increases the leaf area, plant height, number of grains per spike, spike length, yield, and grain zinc content [69]. It also concluded that plant fresh weight increased by zinc spray. According to literature studied by Gite et al. [54], it is observed that ZnSO4.H2O and ZnSO4.7H2O significantly increase the wheat biomass, yield, and zinc contents in grain. The study by Ma et al. [68] revealed that the soil application of zinc in wheat grown under rainfed conditions during severe drought increased grain yield and zinc concentration by 28.2 and 32.8% respectively. Furthermore, the scientist showed that zinc fertilization plays an important role in alleviating drought stress in wheat plants by increasing zinc fertilization in photosynthetic pigment and active oxygen-scavenging substances.

3.3 Plant Resistance to Water Stress

3.3.1 Zinc fertilization

To overcome the zinc deficiency in the soil, zinc-containing fertilizers are spread or sprayed on the surface of the soil, side dressed in standing crop, applied as foliar sprays, used as a seed coating, and in case of transplanted rice plants by dipping the roots before transplanting [64]. Zinc sulphate is the most commonly used fertilizer compound ($Zn\ SO_4 \cdot 7H_2O$ with 27% Zn, and $Zn\ SO_4 \cdot 7H_2O$ containing 33% Zn.

3.4 Effect of Foliar Zinc on Grain Weight

Grain weight play major role in health of grain and crop yield. Different scientists work on This parameter. The study of Amanullah et al. [75] on Integrated foliar nutrients application improve wheat (*Triticum Aestivum* L.) productivity under calcareous soils in drylands revealed that foliar application of zn + boron by the rate of (0.2%) at booting stage of wheat grown under calcareous soil of semiarid region increase the grain weight and more spikelet's spike^{-1} higher grain yield [74].

3.5 Effect of FOLIAR ZINC on Grains Spike^{-1}

The study of Esfandiari et al. [76] on Impact of foliar zinc application on agronomic traits and grain quality parameters of wheat grown in zinc deficient soil revealed that the foliar application of zinc sulfate at booting and milking stage significantly increase the number of grains spike^{-1}. Furthermore, it also found that by the application of zinc sulphate agronomic traits also increased.

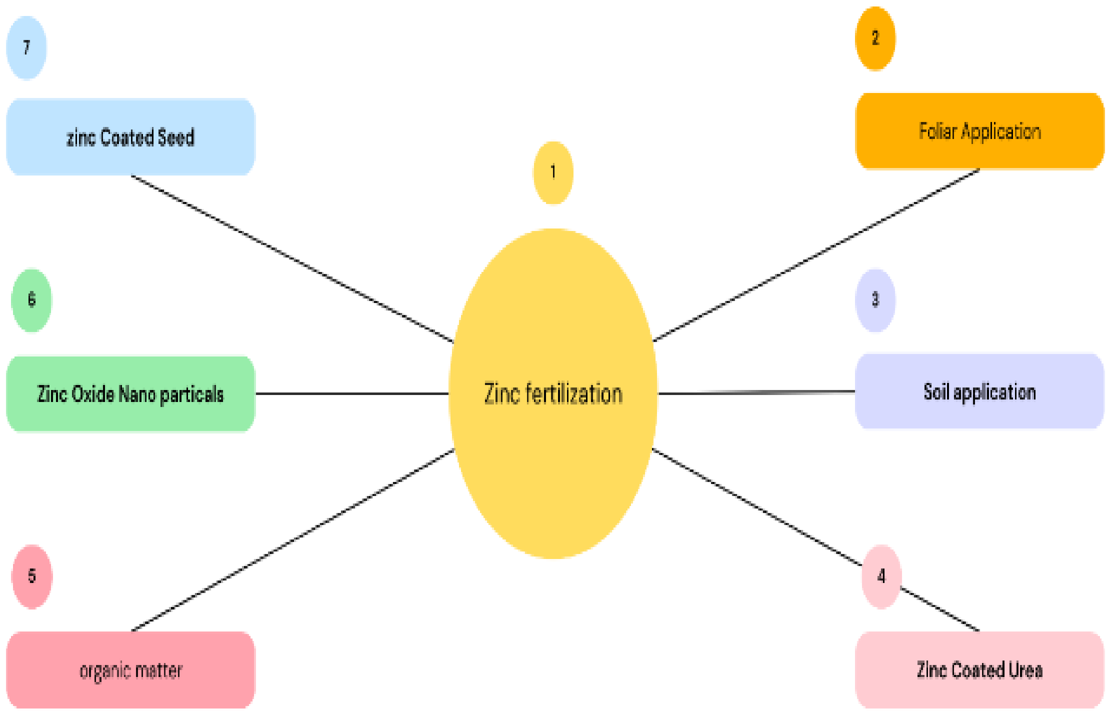


Fig. 1. Effect of zinc fertilization

4. CONCLUSION

The results of the review revealed that foliar application of zinc has significant influences on improvement in the zinc content of the wheat grain and it should be implemented to address zinc deficiency in areas where it is prevalent. The outcome also revealed that zinc treatment leads to a significant increase in wheat yield, demonstrating its influence to improve agricultural productivity in rain-fed farming systems. Finally, it can be stated that it has the potential for further research on optimizing the application rate and timing of foliar zinc application that will enhance wheat production under rain-fed conditions in Pakistan.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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