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Impact of zinc foliar spray on maize (*Zea mays* L.) growth, yield and nutrient uptake

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Abstract
Foliar application of zinc, which involves directly spraying solutions containing zinc onto the leaves to facilitate quick absorption and use by the plant, is an efficient way to correct zinc deficiency in maize (*Zea mays* L.). When applied in situations where soil-based zinc treatments are less successful because of things like high pH or calcareous soils, this approach has been demonstrated to dramatically improve maize growth, yield, and nutritional quality. Chlorophyll production depends on zinc, and zinc applied topically can increase the amount of chlorophyll, enhancing photosynthesis and producing healthier, greener plants. An agronomic technique that is very successful in improving maize's growth traits, yield, and nutrient quality is applying zinc foliarly. By addressing zinc deficiency in this way, food security is increased, sustainable agricultural practices are supported, and maize cultivation growth is economically boosted. The long-term viability and success of maize farming depend on these approaches being optimized through more study and field testing.

Keywords: Zinc, foliar application, growth, yield, nutrient quality

Introduction
Maize (*Zea mays* L.), a major crop in India, is one of the essential to India's food security and economic stability since it is the country's third-most significant cereal crop, after wheat and rice. The crop is essential for direct consumption as well as industrial usage due to its adaptation to various agro-climatic conditions, nutritional value, and flexibility. As per the Directorate of Maize Research (DMR), the yearly output of maize in India surpasses 28 million tonnes, and it is grown on around 9 million hectares (DMR, 2023) [10]. Millions of Indian farmers depend heavily on maize as their major crop for a living, especially in areas like Madhya Pradesh, Tamil Nadu, Karnataka, Andhra Pradesh, and Rajasthan. Beyond just being used for food, the crop has significant economic value. It is a vital component of many companies, such as those that produce biofuels, starch, sweeteners, and animal feed, supporting a number of economic sectors (Shiferaw *et al*., 2011) [32]. Furthermore, the increasing need for maize in the cattle and poultry industries has increased output, making it a desirable commodity in both local and foreign markets (FAO, 2021) [15]. The strategic measures taken by the government to increase maize yield and output highlight the crop's importance to the Indian economy. Increasing the crop's contribution to the national economy has been made possible in large part by policies that support research and development, strengthen supply chains, and increase maize output (ICAR, 2020) [16].

Maize stands out as a critical component of growth and wealth as India works to modernize and sustain its agricultural sector. A vital micronutrient, zinc (Zn) is necessary for the growth and development of maize plants. Its role in several physiological processes, including as protein synthesis i.e. it maintains the molecular stability of ribosomes, DNA, and RNA (Broadley *et al*., 2007) [5]; enzyme activation i.e. carbonic anhydrase and superoxide dismutase are the two enzymes essential for photosynthesis and antioxidant defense mechanisms (Alloway, 2008) [2]; and the preservation of biological membrane structural integrity, highlights its importance.

Zinc deficiency is common in soils, especially in calcareous, sandy, and heavily worn soils, despite its significance. This results in poor crop development and worse nutritional quality (Cakmak, 2008) [7].

Because zinc is essential for human health and influences immunological function, growth, and development, a zinc shortage in crops not only reduces agricultural output but also poses a serious risk to public health (Hotz & Brown, 2004). Insufficient zinc levels in maize can cause a number of negative outcomes, including as stunted growth, chlorosis (leaf yellowing), and decreased grain yield and quality influencing the total economic returns of growing maize (Prasad *et al.*, 2012) [28].

Mechanisms of Stunted growth caused by Zinc Deficiency

- Reduced Elongation and Division of Cells: Zinc is essential for DNA synthesis, cell division, and elongation. Reduced plant height and smaller leaves result from these processes being hampered by a zinc deficit (Marschner, 2012) [25].
- Hormonal Imbalances: Auxins are plant hormones essential for controlling growth, and zinc plays a role in their production. Plant architectural abnormalities and reduced development can occur from deficiencies in zinc, which can also alter auxin synthesis.
- Reduced Photosynthesis: The structural and functional integrity of chloroplasts depends on zinc. Deficiency can restrict the amount of energy available for development by reducing the efficiency of photosynthetic processes and chlorophyll production (Alloway, 2008) [2].
- Alternation in enzyme activity: Plants subjected to zinc deficiency display alterations in the activity of many enzymes and decreased protein synthesis. Foliar spray of nutrient fertilizers at the critical stages of rainfed condition, application of micronutrients and secondary nutrients has been great focus in boosting up the productivity (Devi *et al.*, 2023) [9].

Applying zinc greatly increased maize production and growth in a field experiment carried out in northern India's zinc-deficient soils. Compared to plants that received supplements of zinc, plants low in zinc were stunted, showing a 30–40% decrease in height (Shivay *et al.*, 2015) [33-34]. Root growth is also hampered by zinc shortage in maize plants, in addition to the above-ground portions. It was found that zinc-deficient maize had poorly established root systems, exacerbating problems with nutrient and water intake and ultimately leading to stunted growth (Liao *et al.*, 2004) [23].

(PDF) Importance of Zinc and Molybdenum for Sustainable Pulse Production in India. Available from: https://www.researchgate.net/publication/374503226_Importance_of_Zinc_and_Molybdenum_for_Sustainable_Pulse_Production_in_India [accessed Jun 17 2024].

Zinc Deficiency-Induced Chlorosis

- Interveinal chlorosis: In maize, this condition is characterized by the yellowing of the tissue between the veins while the veins themselves stay green. It is one of the principal signs of zinc deficiency in maize. The younger leaves at the top of the plant make this particularly apparent (Marschner, 2012) [25]. It was found that young leaves of maize plants cultivated in soils lacking in zinc showed significant interveinal chlorosis. Low levels of organic matter content and a high pH of the soil caused the yellowing to be more noticeable (Hafeez *et al.*, 2013) [17].
- Necrosis and Bronzing: In more severe zinc deficient situations, the chlorotic sections may become bronze in color and finally turn necrotic, resulting in regions of dead tissue on the leaves (Alloway, 2008) [2]. It was found that considerable bronzing and necrosis on the leaves of maize fields with low soil zinc levels had a substantial negative impact on the overall health and yield of the plants (Cakmak 2008) [7].

Impact of foliar spray of zinc on growth characteristics of maize

Zinc deficiency in maize (*Zea mays* L.) may be effectively addressed by foliar applying zinc. With this technique, a zinc-containing solution is sprayed directly onto the leaves, enabling quick uptake and instantaneous plant use. It has been demonstrated that foliar zinc administration greatly improves maize growth, yield, and nutritional quality. It enhanced the development and growth as foliar sprays are a rapid and efficient way to immediately remedy zinc deficits in maize plants, particularly in cases where soil conditions like high pH or calcareous soils make soil treatment less effective (Cakmak, 2008) [7]. Zinc is necessary for the creation of chlorophyll, and applying it topically can raise the amount of chlorophyll. This facilitates photosynthesis and results in healthier, greener plants (Ali *et al.*, 2013) [1].

Growth hormones, or auxins, such indoleacetic acid, are produced with the help of zinc. As a result, it contributes to the growth and development of the plant by lengthening the internodes. Growth of maize was enhanced by the use of zinc fertilizer (Suganya *et al.*, 2020) [37]. Tryptophan synthesis in plants is a precursor to the production of growth regulators such as auxin, indole acetic acid, and cytokinin, which are important for cell division, elongation, and root growth. These growth regulators enhance crop growth and nutrient uptake, which in turn increases vegetative growth and ultimately promotes DMP. This may explain zinc's beneficial effect on DMP. The use of zinc fertilizer boosted the growth of leaf, shoot, and root, which in turn increased the production of dry matter (Amanullah *et al.*, 2011; Eltelib, Hamad, and Ali 2006; Eraslan, Cicek, and Guneri 2004; Singh and Singh 1995) [3, 11, 12, 35].

Deswal and Pandurangam (2018) [8] carried out a pot experiment to investigate how several morphophysiological and biochemical parameters of maize were affected by foliar spray micronutrients (zinc, iron, and boron). Three replications of the experiment were run using a completely randomized design (CRD), with T0 being the control (no spray), T_1, T_2 (zinc as form ZnSO4 [0.5%, 1% resp.]), and T_3, T_4 (fe as form FeSO4) at 0.5% and 1%, respectively. Treatments T_5 and T_6 include 0.3% and 0.6% of boron (B as boric acid), respectively. The greatest rise in dry matter was obtained with T_2 treatment (Zn 1%) 91.67% and 87.38% after first and second treatment, respectively, with regard to the control values of total dry matter per plant of 4.40 g and 5.23 g at two development stages (40, 50 DAS, respectively). Kumar *et al.*, (2016) [21] reported similar outcomes. There has been a discernible rise in the production of plant hormones like auxin, which directly stimulate plant growth, as a result of micronutrient foliar treatment (Zn).

Hong and Ji-yun (2007) [18] also carried out a study to examine the combined effects of soil moisture and applied zinc (Zn) on plant development and Zn absorption in maize (Zea mays L.) plants. They investigated using pot experiments in greenhouse settings using the maize variety Zhongdan 9409 in five Zn treatments (0, 3.0, 9.0, 27.0, and 81.0 mg Zn kg^{-1} soil) on cumulic cinnamon soil. Plant development appeared to be unaffected by variations in zinc application rates, ranging from 3.0 to 81.0 mg Zn kg^{-1} soil. Zn treatment and sufficient watering increased the shoots' dry matter weights.

Potarzycki and Grzebisz (2009) [27] conducted a research on the effect of zinc foliar application on grain yield of maize and its yielding components. Farmers' actual maize harvest yields are significantly lower than the grown varieties' potential yields. Zinc was shown to be one of the primary variables limiting maize crop development and yields among several other growth parameters. In a three-year field research, this idea was confirmed by applying zinc fertilizer to maize plants while they were in the fifth leaf stage. Two of the three years of the study showed a substantial response in the maize crop to the zinc foliar spray. For a notable increase in grain output, a zinc foliar spray rate of 1.0 to 1.5 kg Zn/ha was shown to be ideal. Comparing the three-year mean grain production gain to the condition that received only NPK fertilization, the increase was around 18%. Grain yield and total N absorption were both considerably boosted in plants treated with 1.0 kg Zn/ha. The enhancement of yield structure components reveals the yield-forming effect of zinc fertilizer. In comparison to the NPK plot, the number of kernels per plant exhibited the strongest response (+17.8%), but it also had the highest dependency on N uptake ($R2 = 0.79$).

Impact of foliar spray of zinc on yield characteristics of maize

One of the key elements preventing growth and yielding is zinc. There might be a 10% drop in yearly output owing to zinc shortage (Subedi *et al*., 2009) [36]. When applied topically, it also demonstrates a significant reaction in terms of corn growth indices and yield components (Tahir *et al*., 2016 and Wasaya *et al*., 2017) [40, 42]. Applying zinc foliarly is a popular agronomic technique to improve maize's (*Zea mays* L.) yield characteristics, particularly in soils lacking in zinc. With this technique, zinc-containing solutions are sprayed directly onto the leaves, allowing for rapid uptake and use by the plant. This study examines the effects of foliar zinc control on several maize production parameters.

Grain Yield

- Increased Kernel Number: One important factor influencing grain production is the number of kernels per ear, which is increased by zinc treatment. It was found that by enhancing fertilization efficiency and pollen viability, zinc fertilization greatly improved the quantity of kernels (Cakmak, 2008) [7].
- Better Grain Filling: Higher kernel weight and improved grain filling are the results of zinc's enhancement of carbohydrate metabolism and transport. Zinc-deficient maize showed worse grain filling and a lower 1000-kernel weight than plants supplied with zinc (Rashid and Ryan 2008) [29].

Kernel Quality

- Protein Content: Applying foliar spray of zinc to maize kernels increases their protein content, hence enhancing their nutritional value. Zinc is necessary for the production of proteins.
- Starch Content: The enzymatic activities involved in starch synthesis are enhanced by foliar zinc management, resulting in an increase in the starch content of the kernels (Cakmak, 2008) [7].

Plant Biomass

- Growth of Shoots and Roots: Zinc deficiency inhibits the growth of shoots and roots, whereas foliar treatment encourages strong development. More shoot biomass and plant vigor are a result of improved root systems, which also improve nutrient and water absorption (Marschner, 2012) [25].
- Leaf Area and Photosynthetic Efficiency: Foliar zinc treatment improves chlorophyll content and leaf area, which enhances photosynthetic efficiency and biomass production.

Hafeez *et al*., (2013) [17] evaluate the impact of foliar zinc application on the yield and quality of maize. Zinc sulfate was applied as a foliar spray at a concentration of 0.5% during the tasseling and silking stages Foliar zinc application increased grain yield by 18% compared to the control. Kernel protein content improved by 12%, and leaf chlorophyll content increased by 25%, indicating enhanced photosynthetic activity.
Shivay *et al*., (2015) [33-34] conducted an experiment to assess the effect of foliar zinc on maize grown in zinc-deficient soils. Foliar sprays of zinc sulfate (0.5%) were applied at critical growth stages. The study found that foliar zinc application increased grain yield by 20%, kernel number per ear by 15%, and 1000-kernel weight by 10%. Additionally, zinc content in grains increased by 30%, enhancing their nutritional value.
Salama *et al*., (2016) [31] evaluate the response of maize to foliar zinc application in calcareous soils. Zinc sulfate was sprayed at 0.5% concentration at the pre-flowering and post-flowering stages. Foliar zinc application led to a 22% increase in grain yield, improved kernel quality, and higher biomass accumulation. The foliar spray also enhanced the zinc content in the leaves and grains.

Impact of foliar spray of zinc on nutrient uptake of maize

Applying zinc foliarly has been shown to be a successful method of reducing crop zinc deficiencies. When compared to soil treatment techniques, foliar sprays enable the direct absorption of zinc through the leaves, resulting in a more rapid and effective repair of deficiencies (Fageria *et al*., 2009) [14]. According to studies, applying zinc topically to maize can increase the quality of its nutrients by raising its zinc content, encouraging better development, and raising the concentration of other important nutrients (Wang *et al*., 2014) [41].
Numerous elements have been identified as contributing to the efficiency of foliar zinc spray in raising the nutritional quality of maize. First of all, foliar sprays can directly and easily supply zinc to the plant by avoiding the soil-root barrier (Rashid & Ryan, 2004) [29]. Second, foliar application can increase the amount of applied zinc that is accessible for plant absorption by lowering the likelihood of zinc fixation in the soil (Alloway, 2009). Additionally, applying zinc topically to the leaves of maize can improve the crop's overall nutrient utilization efficiency, which will improve growth and the nutritional value of the grains that are harvested (Kaya & Higgs, 2002) [20].

Enhancement of Nutrient Absorption in Maize by Foliar Zinc Administration

- **Enhanced Zinc Uptake and Redistribution**
  A study by Erenoglu *et al*., (2002) [13] demonstrated that foliar zinc treatment was a successful way to increase zinc absorption and redistribution in corn. In this experiment, tasseling maize leaves was done with a 0.5% zinc sulfate solution. The zinc content in the leaves and grains increased significantly, as demonstrated by the data, suggesting that the plant efficiently absorbed and relocated zinc.
- **Improved Nitrogen and Phosphorus Uptake**
  Sui *et al*., (2013) [39] examined the effect of applying zinc topically on maize's absorption of other vital minerals. They discovered that applying a 0.3% zinc sulfate solution topically improved the absorption of phosphorus (P) and

nitrogen (N) in addition to raising the concentration of zinc in the leaves and grains. Zinc's function in root growth and enzyme activation, which promotes the absorption of other nutrients, is probably the cause of this synergistic impact.

- **Increased Micronutrient Uptake**
  Mousavi *et al*., (2013) [26] investigated how applying zinc topically to maize affected the plant's ability to absorb certain micronutrients. At the tasseling stage, the research used a 0.4% zinc sulfate solution. The results showed that zinc, iron (Fe), and manganese (Mn) were better absorbed, underscoring the wider effects of foliar zinc administration on maize's micronutrient profile.

Optimization of Foliar Zinc Application for Improved Nutrient Uptake

Several elements must be addressed in order to enhance the effects of foliar zinc administration in boosting nutrient absorption. These include:

- **Concentration and Frequency**
  Crucial elements include the zinc solution's concentration and how frequently it is applied. According to research, zinc sulfate concentrations between 0.3% and 0.5% are usually beneficial. Several applications throughout critical development stages, such as the vegetative and tasseling stages, might further improve nutrient absorption (Erenoglu *et al*., 2002 and Sui *et al*., 2013) [39].
- **Timing of Application**
  For optimal nutrient absorption, foliar spray timing is essential. By applying zinc to plants at times of active growth, such the vegetative and reproductive stages, you can make sure that they can make the best use of the nutrient (Alloway, 2008) [2].
- **Environmental Conditions**
  The rate of absorption and effectiveness of foliar zinc sprays can be affected by environmental conditions, including temperature, humidity, and wind speed. To guarantee optimal nutrient absorption, the best conditions for foliar treatment should be determined and applied (Fageria *et al*., 2009) [14].

Plant nutrient uptake is determined by two factors: the first is the input of nutrients from the soil, which is represented in the concentration of nutrients in various plant parts; the second is the buildup of dry matter. The initial stage of zinc's transfer from soil to grain was root zinc absorption. Zn absorption has often been calculated as the product of root dry weight and Zn concentration. To enhance the collection of immobile zinc, root surface area (RSA) and root length density should be raised. Adding fertilizer containing zinc may raise the amount of DTPA-Zn (available zinc) in the soil, which might therefore impact the morphology of roots, including RDW and RSA (Rose *et al*., 2013) [30].

Numerous variables influence the root's subsequent translocation to the shoot after absorbing zinc (Xue *et al*., 2014) [44]. Zinc accumulates in grain when zinc from shoots is remobilized and continues to be absorbed by shoots during the grain filling stage (Impa *et al*., 2013; Waters *et al*., 2009) [19, 43]. Because environmental stressors such low Zn availability in the soil, high $CaCO_3$ concentration, high soil pH, and drought can restrict shoot Zn absorption during grain filling, zinc remobilization is essential for the accumulation of zinc in grain (Kutman *et al*., 2012) [22]. The improved zinc absorption in maize was facilitated by the elevated soil zinc nutrient status (Ayyar and Appavoo 2017; Suganya and Saravanan 2016) [38].

There are two sources of zinc in grain: recently acquired zinc that is transferred straight to kernels during the grain filling stage (via transportation from root without first being stored in shoot); and less recently acquired zinc that has been stored in shoot and is then transferred (remobilized) to grain. Whereas the second source depicts preanthesis remobilization, the first source shows post anthesis shoot uptake. Plants have trouble absorbing zinc when soil or climatic circumstances limit zinc availability; zinc absorption in postanthesis shoots may also be reduced; and zinc in grain mostly comes from the remobilization of zinc from vegetative components (Xue *et al*., 2012; Liu *et al*., 2019) [45, 24]. However, the primary source of zinc in grain under Zn-sufficient circumstances is shoot absorption of Zn during grain filling (Impa *et al*., 2013; Zou *et al*., 2019) [19, 46].

Conclusion

In conclusion, maize is an essential crop for India's agricultural and financial environments. The government is taking deliberate steps to boost maize output and yield, which is in line with the crop's economic significance, as India works to modernize and maintain its agriculture industry. The contribution of maize to the national economy has increased dramatically as a result of policies that encourage R&D, improve supply networks, and raise productivity levels. To optimize nutrient absorption and plant health, an ideal foliar zinc treatment takes into account the concentration, timing, frequency, and environmental factors. In addition to treating zinc deficiency, this calculated technique promotes economic expansion and sustainable agriculture methods. Zinc deficiency may be addressed by foliar spray, which greatly improves maize growth, yield, and nutritional quality. This highlights the significance of zinc in maintaining food security, sustaining farmer livelihoods, and promoting industrial and economic development. In order to maintain the sustainability and prosperity of maize growing in India, more study and field testing will be conducted to further enhance these techniques.

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