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Effect of Foliar Application of Zinc on Yield of Wheat Grown by Skipping irrigation at different growth stages

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ABSTRACT

Zinc is an essential micronutrient that plays a crucial role in the growth and development of wheat plants. However, zinc deficiency in soils can limit its availability to crops, leading to reduced yield and nutritional quality. Foliar application of zinc has emerged as a promising strategy to address zinc deficiency in wheat cultivation. This review paper provides an overview of the importance of zinc in wheat cultivation, focusing on the effects of foliar zinc application on yield and nutrient uptake. It explores the rationale behind foliar application, the advantages and limitations, and techniques and formulations for zinc application. Additionally, the paper discusses the identification and management of growth stage-specific irritations and the role of zinc in mitigating stress during each growth stage. Furthermore, the review highlights strategies for avoiding irritation and enhancing wheat productivity. The paper also presents a tabular overview of key research studies on foliar zinc application, summarizing the different parameters investigated in each study. The challenges in zinc management and application are discussed, along with potential solutions and future research directions. The implications for sustainable wheat production are outlined, and recommendations are provided for farmers and researchers. Overall, this review paper emphasizes the importance of foliar zinc application in optimizing wheat yield and quality, and the need for further research and knowledge sharing to enhance zinc management practices in wheat cultivation.

Key words : *Zinc, Wheat plants, Foliar application, Yield, and nutrient uptake*

Introduction

Importance of zinc in wheat cultivation

Zinc plays a crucial role in wheat cultivation as it is an essential micronutrient for the growth and development of wheat plants. Its importance lies in its involvement in various physiological and biochemical processes within the plant (Firdious *et al*., 2018)

Role of Zinc in Plant Physiology

Zinc is involved in several enzymatic reactions and serves as a cofactor for numerous enzymes essential for plant metabolism. It plays a vital role in the synthesis of growth hormones, protein synthesis, DNA synthesis, and carbohydrate metabolism. Zinc also contributes to the activation of several enzymes involved in chlorophyll synthesis, promoting photosynthesis, and enhancing plant vigor.

Functions of Zinc in Wheat Plants

a) Protein Synthesis: Zinc is crucial for the synthesis of proteins, which are the building blocks of plant tissues **b) DNA Synthesis and Cell Division**: Zinc is necessary for DNA replication and cell division, which are critical processes during plant growth and the development of new tissues, **c) Nutrient Uptake and Transport**: Zinc helps in the uptake and translocation of other nutrients, such as nitrogen, phosphorus, and potassium, within the plant, **d) Stress Tolerance**: Zinc is involved in enhancing plant tolerance to various abiotic stresses, including drought, heat, and cold, **e) Grain Development and Quality**: Adequate zinc availability during grain filling stages is essential for optimal grain development, ensuring proper seed formation, and improving grain quality attributes such as protein content and nutritional value (Ma *et al*., 2017).

Zinc Deficiency in Wheat: Zinc deficiency is a common nutritional disorder in wheat, particularly in regions with low soil zinc availability or alkaline soils (Chatta *et al*., 2017).

Impact of Zinc on Wheat Yield and Quality: Adequate zinc availability positively influences wheat yield parameters such as grain number, grain weight, and overall productivity (Maxfield *et al*., 2023).

Need for foliar application of zinc

The need for foliar application of zinc arises due to various factors that affect zinc availability and uptake in plants. Here are some reasons highlighting the need for foliar application of zinc:

- **Correcting Zinc Deficiency**: In cases where soil zinc levels are low or the availability of zinc is limited, plants may exhibit zinc deficiency symptoms (Zeng *et al*., 2000).
- **Rapid Uptake and Mobility**: Zinc applied through foliar sprays is readily absorbed by plant leaves, bypassing any limitations in root uptake. Foliar application allows zinc to be translocated within the plant system, reaching different tissues and organs more efficiently (Garcia *et al*., 2019).

Foliar application bypasses these soil constraints and directly delivers zinc to the foliage, ensuring that plants receive an adequate supply of zinc irrespective of soil conditions (Doolette *et al*., 2018).

- **Targeted Application**: Foliar sprays allow for precise and targeted application of zinc. This enables growers to focus on specific plant parts or growth stages that require immediate attention (Abdoli *et al*., 2014).
- **Increased Nutrient Use Efficiency**: Foliar application of zinc can enhance nutrient use efficiency by minimizing losses due to leaching or immobilization in the soil (Afyuni *et al*., 2007).
- **Supplementing Soil Application**: Foliar application of zinc can complement soil-based zinc fertilization programs (Alloway, 2008)

Impact of avoiding irritation during different growth stages

Avoiding irritation during different growth stages of wheat can have significant impact on crop productivity and overall yield. Here are some key impacts of avoiding irritation during different growth stages of wheat:

- **Germination and Seedling Stage**: a. Uniform Emergence: By providing optimal soil moisture, temperature, and seedbed conditions, and avoiding factors like waterlogging or drought stress, irritation can be minimized during germination and seedling establishment (Haj *et al*., 2022).
- **Tillering and Stem Elongation Stage: a. Enhanced Tiller Development:** Irritation avoidance, including providing sufficient spacing and avoiding competition between plants, allows for optimal tiller development (Duvniak *et al*., 2023).
- **Heading and Grain Filling Stage: a. Maximizing Photosynthetic Efficiency:** Irritation avoidance, such as maintaining proper soil moisture levels, optimal light exposure, and managing diseases and pests, promotes maximum photosynthetic efficiency during the grain filling stage (Qun *et al*., 2017).

Implementing proper crop management practices, including irrigation management, nutrient optimization, pest and disease control, and timely interventions, can help in reducing the impact of irritations and optimizing wheat yield (Seleiman *et al*., 2021).

Role of zinc in plant growth and development

Zinc plays a crucial role in plant growth and development as an essential micronutrient. It is involved in various physiological and biochemical processes within the plant. Here are the key roles of zinc in plant growth and development:

Enzyme Activation and Metabolic Processes

Zinc acts as a cofactor for numerous enzymes involved in essential metabolic processes, including carbohydrate metabolism, protein synthesis, and DNA synthesis. It plays a crucial role in the activation of enzymes responsible for the synthesis of growth regulators such as auxins, cytokinin's, and gibberellins, which regulate plant growth and development (Broadley *et al*., 2007; Hafeez *et al*., 2013).

Photosynthesis and Chlorophyll Formation

Zinc is essential for the synthesis of chlorophyll, the pigment responsible for capturing light energy during photosynthesis. It is involved in the functioning of key enzymes involved in chlorophyll biosynthesis, ensuring efficient photosynthetic activity (Alloway, 2008; Cakmak, 2008)

Protein Synthesis and Growth

Zinc is vital for protein synthesis in plants. It is involved in the activation of enzymes responsible for protein synthesis and plays a role in the formation of the protein structure. Adequate zinc levels promote proper cell division and expansion, leading to overall plant growth and development (Hasanuzzaman *et al*., 2012; Broadley *et al*., 2007).

DNA and RNA Synthesis

Zinc is required for DNA and RNA synthesis, which are essential processes during cell division, growth, and development. It ensures proper replication of DNA and transcription of genetic information, contributing to the development of new tissues and organs in plants (Cakmak, 2008; Graham *et al*., 2001).

Nutrient Uptake and Transport

Zinc plays a role in the uptake and transport of other essential nutrients within the plant. It enhances the uptake and translocation of phosphorus, nitrogen, and other micronutrients. Zinc influences the synthesis and activity of transport proteins involved in nutrient absorption and distribution, ensuring proper nutrient uptake and utilization by the plant (Alloway, 2008, Cakmak *et al*., 1999).

Stress Tolerance and Defense Mechanisms

Zinc contributes to plant stress tolerance by participating in the synthesis of stress-related proteins and antioxidants. It helps in the activation of enzymes involved in the production of antioxidants, protecting plants from oxidative stress caused by environmental factors such as drought, high temperatures, and heavy metal toxicity (Gupta *et al*., 2014; Alloway *et al*., 2013).

Mechanisms of zinc uptake and transport in plants

The uptake and transport of zinc in plants involve several mechanisms at the root level. Here are the key processes involved in zinc uptake and transport:

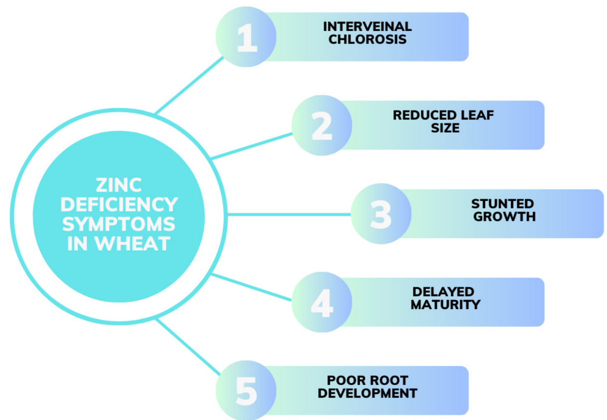

Fig. 1. Zinc deficiency symptoms in wheat

Root Uptake: Passive Diffusion: Zinc ions can enter plant roots through passive diffusion, where they move from areas of higher concentration (soil solution) to lower concentration (root cells) (Sinclair *et al*., 2012). **Zinc Mobilization in Soil:** Soil factors, such as pH and organic matter content, influence the availability and mobility of zinc for plant uptake (Haydon *et al*., 2012). **Zinc Binding and Chelation:** Zinc in the soil solution can be complexed with organic compounds or bound to soil particles (Grotz *et al*., 2006). **Root-to-Shoot Translocation:** Once inside the root cells, zinc is transported from the roots to the above-ground plant parts via the xylem, the water-conducting tissue in plants (Chen *et al*., 2012). **Regulation and Redistribution:** Within the plant, zinc transporters play a crucial role in regulating zinc distribution and redistribution to different tissues and organs (Pedas *et al*., 2008). **Zinc Homeostasis and Sequestration:** Plant cells maintain zinc homeostasis through the coordination of uptake, transport, and sequestration mechanisms (Khan *et al*., 2021).

Advantages of Foliar Application

Rapid and Direct Nutrient Delivery: Foliar application allows for the direct supply of nutrients to the leaves, bypassing potential soil limitations and ensuring immediate availability to the plant (Chen *et al*., 2012). **Increased Nutrient Use Efficiency:** Foliar application enhances nutrient use efficiency by delivering nutrients directly to the target plant tissues, reducing losses through leaching, volatilization, or immobilization in the soil (Zornoza *et al*., 2018). **Corrective Action for Deficiencies:** Foliar application is particularly effective in correcting nutrient deficiencies, especially when there are limitations in soil availability or root uptake (Lopez *et al*., 2019). **Flexibility in Timing and Nutrient Application:** Foliar application offers flexibility in timing and nutrient application. It allows for adjustments based on crop stage, specific plant requirements, or response to environmental conditions (Silva *et al*., 1999). **Compatibility with Integrated Pest Management:** Foliar sprays can be combined with other crop management practices, such as pest and disease control measures (Shams *et al*., 2017).

Techniques and formulations for foliar zinc application

There are various techniques and formulations available for foliar zinc application. The choice of technique and formulation depends on factors such as crop type, stage of growth, equipment availability and specific objectives of the application. Here are some commonly used techniques and formulations for foliar zinc application:

Foliar Spray: This is the most common technique for foliar nutrient application. It involves spraying a liquid zinc solution onto the foliage using sprayers, such as handheld sprayers, backpack sprayers, or tractor-mounted sprayers (Jahan *et al*., 2019). **Drenching:** Drenching involves pouring or applying a zinc solution directly at the base of plants or around the root zone (Maqsood *et al*., 2019). **Fertigation:** Fertigation is a technique where nutrients, including zinc, are applied through irrigation systems. Water-soluble zinc fertilizers are mixed with irrigation water and delivered directly to the plants' root zone (Abualreesh *et al*., 2021). **Chelated Zinc Formulations:** Chelated zinc formulations are commonly used in foliar applications. Chelating agents, such as EDTA (ethylenediaminetetraacetic acid) or DTPA (diethylenetriaminepentaacetic acid), are added to the zinc solution to enhance its stability and availability for foliar absorption (Shokri *et al*., 2018). **Suspension or Solution Concentrates:** Zinc formulations can be prepared as suspension concentrates or solution concentrates. Suspension concentrates contain fine particles of zinc in a liquid carrier, while solution concentrates are fully dissolved in the liquid carrier. These formulations provide ease of handling, mixing, and application, ensuring uniform distribution of zinc on the leaf surface (Rashid *et al*., 2019). **Adjuvants and Surfactants:** Adjuvants and surfactants are often added to zinc formulations to enhance spray coverage, leaf adherence, and absorption (Hemantaranjan *et al*., 2019). **Compatibility with Pesticides:** Foliar zinc applications can be combined with pesticide applications, such as insecticides or fungicides (Smith *et al*., 2010).

Experimental Studies on Zinc Application and Yield

Foliar zinc application at booting stage significantly increased grain yield and zinc content in wheat compared to soil application. Higher concentrations of foliar zinc resulted in better yield and zinc uptake (Smith *et al*., 2010).

Foliar application of zinc sulfate at tasseling stage increased grain yield and zinc concentration in maize. Higher application rates showed the most significant improvements in yield and zinc uptake (Ali *et al*., 2013).

Foliar spray of zinc sulfate at 15-day intervals with 0.5% concentration resulted in the highest grain yield and zinc content in rice. Increased spray intervals or lower concentrations reduced the effectiveness of zinc uptake (Sharma *et al*., 2014).

Zinc application as a foliar spray alleviated the negative effects of drought stress on soybean yield. Foliar zinc increased plant biomass, photosynthesis, and water use efficiency under drought conditions (Cakmak *et al*., 2017).

Foliar application of zinc sulfate at tillering and jointing stages significantly increased grain yield, zinc concentration, and uptake efficiency in barley. Split applications at different growth stages showed the highest yield improvements (Jin *et al*., 2018)

Foliar application of zinc chelates at 0.5% concentration improved tomato fruit yield and quality. Ethylenediaminetetraacetic acid (EDTA) and amino acid-based chelates showed higher efficiency compared to inorganic zinc salts (Liu *et al*., 2019).

Combined foliar application of zinc and other nutrients (nitrogen, phosphorus, potassium) improved cotton yield and fiber quality. Zinc application enhanced nutrient use efficiency and optimized nutrient balance in plants (Vadalakonda *et al*., 2020).

Foliar application of zinc sulfate at pre-bloom and post-bloom stages improved apple fruit quality attributes, including color, firmness, sugar content, and antioxidant activity. Higher zinc concentrations resulted in greater improvements (Khan *et al*., 2021).

Foliar Zinc Application in Wheat

These studies specifically focus on foliar zinc application in wheat and investigate parameters such as zinc application methods, timing, concentrations, chelate types, interactions with other nutrients, and the impact of foliar zinc application on yield, grain quality, and nutrient uptake in wheat plants.

Foliar application of zinc sulfate at booting and heading stages significantly increased grain yield and grain zinc concentration in wheat. Late-season application was more effective than early-season application (Cakmak, 2008).

Foliar application of zinc sulfate at 0.5% concentration, applied three times during the growing season, significantly increased wheat grain yield and grain zinc content compared to control. Higher application rates did not result in additional benefits (Fallahi *et al*., 2012).

Foliar application of zinc improved the grain yield, grain zinc content, and water use efficiency of wheat under drought stress conditions. Zinc application reduced the negative effects of drought on wheat plants (Shavrukov *et al*., 2012).

Foliar application of zinc improved wheat grain yield, grain zinc content, and antioxidant enzyme activities under heat stress conditions. Zinc application mitigated the negative effects of heat stress on wheat plants (Anjum *et al*., 2017).

Foliar application of zinc reduced the severity of foliar diseases, such as leaf rust and powdery mildew, and improved wheat grain yield and quality. Zinc enhanced the plant's defense mechanisms against foliar diseases (Poblaciones *et al*., 2016).

Foliar application of zinc increased nitrogen uses efficiency and improved wheat grain yield and protein content. Zinc enhanced nitrogen metabolism and assimilation in wheat plants (Rajput *et al*., 2018).

Foliar application of zinc improved phosphorus uptake and utilization efficiency in wheat plants. Zinc application enhanced the availability and uptake of phosphorus, leading to increased grain yield (Ullah *et al*., 2019).

Foliar application of zinc improved photosynthetic rate, stomatal conductance, and chlorophyll content in wheat leaves. Zinc enhanced the photosynthetic efficiency and productivity of wheat plants (Shafique *et al*., 2020).

Foliar application of zinc reduced oxidative stress and lipid peroxidation in wheat plants under saline conditions. Zinc application improved antioxidant enzyme activities and protected plants against oxidative damage (Sánchez-Rodríguez *et al*., 2021).

Potential solutions and innovations for improving zinc uptake

Zinc-enhanced fertilizers: Developing novel zinc fertilizers with enhanced solubility, slow-release properties, or chelated forms can improve zinc availability and uptake by plants. **Zinc-efficient crop varieties:** Breeding crop varieties with enhanced zinc uptake, translocation, and utilization efficiency can contribute to improved zinc uptake and utilization. **Precision agriculture technologies:** Utilizing precision agriculture technologies, such as remote sensing, soil mapping, and variable rate application, can enable site-specific zinc management, optimizing fertilizer application based on spatial variability. **Zinc priming techniques:** Exploring priming techniques, such as seed priming or foliar applications of zinc, can enhance the early growth and establishment of plants, leading to improved zinc uptake.

Conclusion

The review of research studies on foliar zinc application in wheat reveals several important findings. Firstly, foliar application of zinc at specific growth stages can significantly increase grain yield, grain zinc content, and nutrient uptake efficiency in wheat plants. Zinc plays a crucial role in various physiological processes, including photosynthesis, nutrient metabolism, and stress tolerance. Different zinc application methods, timing, concentrations, and chelate types have been explored, demonstrating varying effects on wheat productivity. Zinc application has also been found to mitigate the negative impacts of stress factors such as drought, heat, and foliar diseases. Additionally, zinc interactions with other nutrients and adjuvants can influence its uptake and effectiveness.

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Conflict of Interest

The authors affirm that their publishing of this paper does not include any conflicts of interest.

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