NANOPARTICLES-NANOZINCAPPLICATION INBARLEY

ABSTRACT

Barley continues to play a crucial role in global agriculture, food production, and human nutrition, underscoring its significance across multiple domains.barley remains crucial in industrial applications, especially in brewing and malting industries, leading to its emergence as a commercial crop with initiatives like contract farming in regions such as Punjab, Haryana, and Rajasthan.Nanoparticle-based delivery systems represent advanced methods for enhancing zinc efficiency in barley plants. These systems utilize nanoscale materials like nanoparticles, nanotubes, or nanocarriers to encapsulate and stabilize zinc ions, improving their bioavailability and uptake by overcoming solubility and mobility barriers in soil. Overall, Nano zinc represents a promising and sustainable solution for combating micronutrient deficiencies and enhancing barley production in diverse agricultural settings. This approach holds significant potential to contribute to global food security and agricultural sustainability in the future.

Keywords: Nanoparticle, agricultural sustainability, food production, nutrition

Keywords: *Hordeumvulgare*,Seedpriming,Nano zinc, Nutrient uptake, Abiotic stress, Growth parameters.

1.INTRODUCTION

Barley, scientifically known as *Hordeum vulgare* and locally referred to as "jau" in India, holds a significant position in global agriculture and human history. Today, Barley ranks fourth among cereal crops worldwide, with a production volume of 155 million tons in 2022, following maize, wheat, and rice, making up approximately 12% of total cereal production (Verma *et al*., 2022). Barley cultivation spans diverse climates, thriving in both tropical and temperate regions. In India, it is predominantly grown in states like Rajasthan, Uttar Pradesh, and Madhya Pradesh (Shekhawat *et al*., 2022). Known for its resilience under rainfed conditions and adaptability to challenging climates such as drought, heat, and cold, barley has earned a reputation as a sustainable cereal crop (Newton *et al*., 2011; Wang *et al*., 2018). Barley is classified into two main genotypes: two-rowed and six-rowed varieties, each serving different purposes. While six-rowed barley is preferred for animal feed due to its higher grain protein content, two-rowed barley is traditionally used for malting, notably in regions like Europe, Australia, and South America (Ozturk *et al*., 2023; Horsley *et al*., 2009).

Beyond its role in agriculture, Barley is versatile in its applications. Approximately 70% of global Barley production is utilized as animal feed, while the remainder supports the production of beer, whisky, and various culinary uses (Edney,1996). Furthermore, barley serves as a valuable crop for green manure, pasture, hay, silage, and as a monoculture, illustrating its multifaceted importance in agricultural systems (Steinbach, 1997). Malting process further enhances barley's utility, involving several stages from steeping and germination to drying and storage, facilitating its transformation into malt for brewing and distillation (Patel *et al*., 2019). By-products from the brewing and malting industries contribute to feed and non-feed products, addressing waste management challenges (Karlovic *et al*., 2020). Moreover, ongoing research explores barley's potential to produce modified starches and cereals with enhanced nutritional profiles, such as high protein or specific starch compositions, meeting dietary demands for vitamins, fibre, and protein (Jadhav *et al*., 1998; Zohoori, 2020). Thus, barley continues to play a crucial role in global agriculture, food production, and human nutrition, underscoring its significance across multiple domains.

2. SIGNIFICANT ADVERSE EFFECTS OF BARLEY PRODUCTION

Adverse environmental conditions pose significant challenges to agricultural production, impacting barley (*Hordeum vulgare*) cultivation in various ways. Drought, salinity, deficiencies in macro and micronutrients, extreme temperatures, frost, flooding, alkaline soils, and mineral deficiencies are among the primary stressors. These factors contribute to reduced yield and quality, particularly affecting six-rowed barley used in malting due to its low carbohydrate content in the endosperm and high husk ratio, exacerbated by inadequate crop management practices such as improper irrigation and fertilizer use, and limited cultivation of suitable malt varieties (Hajiboland, 2012).

However, barley remains crucial in industrial applications, especially in brewing and malting industries, leading to its emergence as a commercial crop with initiatives like contract farming in regions such as Punjab, Haryana, and Rajasthan (Kumar *et al*., 2014). Nevertheless, the resilience of barley plants to environmental stresses, including drought, has been explored through genetic variation and the identification of drought-tolerant genotypes (Bukhari *et al*., 2019; Serraj*et al*., 2011).Salinity is prevalent in arid and semi-arid regions and coastal areas with low-quality irrigation water, poses another significant challenge to barley production, particularly affecting germination and early seedling stages (Pulido-Bosch *et al*., 2018; Fan *et al*., 2014). Barley's response to salt stress is primarily characterized by ionic effects rather than osmotic stress (Mahlooji*et al*., 2018). Strategies to mitigate these stresses include the application of potassium nitrate (KNO3) to alleviate oxidative stress and maintain favourable physiological parameters such as reduced malondialdehyde (MDA) content and altered Na+/K+ ratios in leaves (Ahmad *et al*., 2022; Sofy *et al*., 2022) (Fig.1).

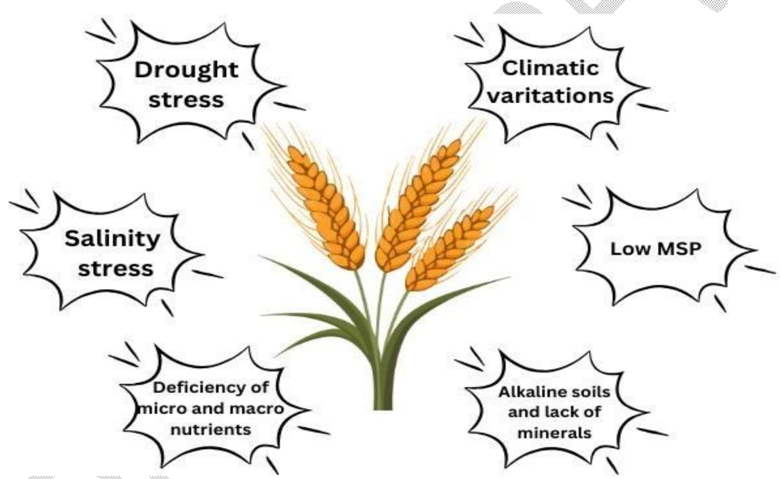

Fig.1. Significantadverseeffects on barley Production

3. SEED PRIMING IN BARLEY

Efficient seed germination is crucial in agriculture and horticulture (Kulkarni *et al*., 2011). Poor germination can lead to uneven seedling growth and substantial financial losses (Bisbis et al., 2018). Seed priming has gained popularity as a method to rejuvenate seeds and enhance agricultural productivity (Marthandan *et al*., 2020), particularly in commercial applications and seed banks aiming for improved germplasm conservation (Farooq *et al*., 2019; Hay and Sershen, 2021).Primed seeds undergo hydration and drying processes to stimulate metabolic activities, enzyme activation, and antioxidant defenses, resulting in faster and more uniform germination compared to unprimed seeds (Jisha *et al*., 2013; Paul *et al*., 2022). Various priming techniques such as Hydro-priming, Halo-priming, Osmo-priming, Bio-priming, Nano-priming, Solid matrix priming, and Hormone priming have been developed to enhance seed germination and reduce environmental stress (Pawar and Laware, 2018).The effectiveness of seed priming depends on factors like oxygen availability, priming agent duration, osmotic potential, temperature, light conditions, aeration, and seed condition, which significantly influence its outcomes across different crops (Lutts *et al*., 2016). Nano-priming, a novel approach, has shown promising results in enhancing growth, yield, and nutritional quality through its activation of Reactive Oxygen Species (ROS), antioxidant mechanisms, and promotion of nanopore formation for improved water absorption and starch hydrolysis (do Espirito Santo Pereira *et al*., 2021; Nile *et al*., 2022).In agriculture, adopting innovative practices like seed priming, including nano-priming, holds potential for revolutionizing crop production to meet future food security and quality challenges (Beddington, 2010).

3.1 Overview of Nanoparticles-Based Delivery Systems

Nanoparticle-based delivery systems represent advanced methods for enhancing zinc efficiency in barley plants. These systems utilize nanoscale materials like nanoparticles, nanotubes, or nanocarriers to encapsulate and stabilize zinc ions, improving their bioavailability and uptake by overcoming solubility and mobility barriers in soil (Khan *et al*., 2019). Engineered nanoparticles can release zinc ions gradually, ensuring sustained nutrient supply to plants while protecting against degradation and leaching, thereby optimizing zinc utilization (Rizwan *et al*., 2019; Zhu *et al*., 2018), (Fig.2).

Types such as zinc oxide nanoparticles (ZnO NPs) effectively deliver zinc to roots, enhancing uptake and translocation within barley and other crops (Eichert *et al*., 2011). Functionalization with biocompatible coatings like chitosan or humic acid improves nanoparticle stability, soil dispersibility, and interaction with plant roots, further enhancing zinc assimilation and crop yield (Rizwan *et al*., 2019; Khan *et al*., 2019).

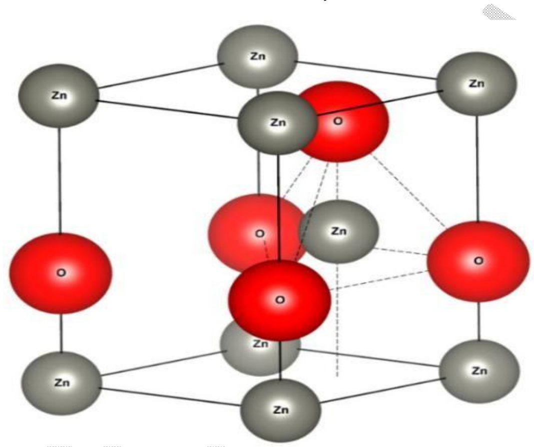

Fig. 2 SchematicillustrationofthewurtziteZnOstructure (Ding*etal.,*2008)

3.2 ImportanceofZincinBarleyGrowthand Development

Zinc is essential for barley growth, acting as a cofactor for enzymes involved in photosynthesis, respiration, and nutrient synthesis (Marschner, 2012). It regulates hormone levels, influencing cell elongation, root development, and flowering (Alloway, 2008). Zinc deficiency can impair DNA synthesis, cell division, and membrane integrity, reducing stress tolerance and overall vigor (Cakmak, 2008). Structurally, zinc maintains cell wall integrity, membrane stability, and ion transport, crucial for nutrient uptake and resilience against environmental stresses (Broadley *et al*., 2007). Barley deficient in zinc shows chlorosis, reduced tillering, and delayed maturity, indicating compromised health and productivity (Marschner, 2012) (Table.1).

Aspect	ImportanceofZincinBarleyGrowthand Development	References
Enzyme Cofactor	➢ Essentialforenzyme activityin photosynthesis, respiration,carbohydrate,protein,andnucleic acid synthesis	Marschner,2012

HormoneRegulation	➢ Involvedinsynthesisandactivationofplant hormoneslikeauxins,regulatingcellelongation,division, and differentiation	Alloway, 2008
DNA Synthesis and Cell Integrity	➢ CrucialforDNA synthesis,celldivision,and membraneintegrity,enhancingplantvigorandstress tolerance	Cakmak, 2008
StructuralIntegrity	➢ Component ofproteins and complexes in cell wallsynthesis,membranestability,andiontransport	Broadley*etal.*, 2007
SymptomsofDeficiency	➢ Barleyplantsexhibitchlorosis,reducedtillering,anddelayedmaturityascharacteristic symptoms of zinc deficiency	Marschner,2012

Table.1.ZincinBarleyGrowthandDevelopment

3.3 EffectsofNanoZinconBarleyGrowth Parameters

Nano zinc positively impacts barley growth parameters, enhancing yield and quality. Studies indicate it promotes root and shoot growth, biomass accumulation, and photosynthetic efficiency (Shahbaz *et al*., 2020; Rehman *et al*., 2019). Barley treated with Nano zinc shows increased root length, surface area, and volume, improving nutrient uptake and water absorption (Shahbaz *et al*., 2020). It also enhances shoot elongation, leaf area, and tillering capacity, boosting overall vigour and biomass production (Rehman *et al*., 2019).

Physiologically, Nano zinc enhances chlorophyll synthesis, photosynthetic rate, and nutrient assimilation in barley (Ghori *et al*., 2019; Shahbaz *et al*., 2020). Additionally, Nano zinc boosts antioxidant enzyme activity, mitigating oxidative stress in barley exposed to drought, salinity, or heavy metals (Rehman *et al*., 2019; Shahbaz *et al*., 2020).Furthermore, Nano zinc influences gene expression related to growth and stress responses, enhancing barley's tolerance to biotic and abiotic stresses (Rehman *et al*., 2019; Ghori *et al*., 2019). This modulation of stress-responsive genes contributes to improved resilience and survival under adverse environmental conditions. Overall, Nano zinc application emerges as a promising strategy to enhance barley productivity and resilience(Table.2).

Aspect	EffectsofNanoZincon Barley Plants	References
Growth Parameters	➢ Enhancesrootandshootgrowth. ➢ Increasesbiomassaccumulation. ➢ Improvesphotosynthetic efficiency.	Shahbaz*etal.,*2020;Rehman *et al.,* 2019
MorphologicalAttributes	➢ Increases root length, surface area, and volume. ➢ Promotesshootelongation andleafarea expansion.	Shahbaz*etal.,*2020;Rehman *et al.,* 2019
PhysiologicalProcesses	➢ Enhanceschlorophyllsynthesisand photosynthetic rate. ➢ Improvesnutrientassimilation ➢ Alleviatesoxidativestress.	Ghori*etal.,*2019;Shahbaz*et al.,*2020;Rehman*etal.,*2019

Table2.NanoZinconBarleyGrowthParameters

3.4. PhysiologicalandBiochemicalResponses ofBarleytoNanoZinc

Nano zinc enhances barley growth and quality by improving root and shoot development, biomass production, and photosynthetic efficiency (Shahbaz *et al*., 2020; Rehman *et al*., 2019). It increases root length, surface area, and nutrient uptake while promoting shoot elongation and tillering capacity (Shahbaz *et al*., 2020; Rehman *et al*., 2019). Nano zinc boosts chlorophyll synthesis, photosynthetic rate, and antioxidant enzyme activity, enhancing barley's resilience to environmental stresses like drought and salinity (Ghori *et al*., 2019; Shahbaz *et al*., 2020). Additionally, it modulates gene expression for improved stress tolerance and overall plant vigor (Rehman *et al*., 2019; Ghori *et al*., 2019). Nano zinc application thus proves beneficial for enhancing barley productivity under challenging agricultural conditions(Table.3).

Aspect	**Physiological and Biochemical Responsesof BarleytoNanoZinc**	**References**
AntioxidantEnzyme Activities	➢ Enhancesactivitiesof antioxidantEnzymes(SOD,CAT, POD)	Ghori*et al.,* 2019; Rehman *et al.,*2019
	➢ Improves scavenging of reactive oxygen species (ROS). ➢ Mitigates oxidative stress.	
Accumulationof Osmolytes and Compatible Solutes	➢ Modulates accumulation of osmolytes (proline, sugars, polyamines). ➢ Facilitates osmotic adjustment and stress tolerance.	Shahbaz *et al*., 2020; Rehman *et al*., 2019
Influence on Plant Hormones	➢ Affects biosynthesis and metabolism of plant hormones (ABA, cytokinins,gibberellins). ➢ Alters physiological processes and stress responses.	Shahbaz *et al*., 2020
Nutrient Uptake and Assimilation	➢ Influences uptake, assimilation, anddistribution of essential nutrients (nitrogen, phosphorus, potassium). ➢ Enhances nutrient uptake efficiency andUtilization.	Rehman *et al*., 2019

Table.3.**PhysiologicalandBiochemicalResponsesofBarleytoNano Zinc**

4. ChallengesandFuturePerspectivesinNanoZincApplicationinBarley

Nano zinc application in barley offers potential benefits for enhancing growth, productivity, and stress tolerance, yet it also presents significant challenges that must be addressed for safe and effective implementation in agriculture. One primary concern is the environmental impact of nanoparticle release into soil and water ecosystems, with potential long-term persistence and bioaccumulation raising issues about toxicity to non-target organisms (Judy *et al*., 2015). To mitigate these risks, rigorous risk assessments and regulatory frameworks are essential to ensure sustainable Nano zinc use.

Understanding the fate of Nano zinc particles in soil-plant systems remains limited, impacting predictions of their effects on soil health, microbial communities, and nutrient cycling (Dimkpa*et al*., 2015). Interactions with soil components like organic matter and minerals affect mobility and bioavailability, necessitating further research to clarify these mechanisms and their implications for biogeochemical processes.Variability in Nano zinc formulations, including particle size, surface chemistry, and coatings, poses another challenge that can influence effectiveness and behaviour in agricultural contexts (Shahbaz *et al*., 2020). Standardized protocols for synthesizing and characterizing Nano zinc are crucial to ensure consistency across studies and facilitate meaningful comparisons.Despite these challenges, Nano zinc shows promise in addressing barley's micronutrient deficiencies and improving crop productivity sustainably. Future research should focus on optimizing formulations, dosage, and application methods to maximize benefits while minimizing environmental risks (Shahbaz *et al*., 2020). Integrating Nano zinc with precision farming, biofortification, and nutrient management strategies could further enhance its efficacy across diverse agroecosystems (Rehman *et al*., 2019).

5. Conclusion

In conclusion, nanoparticle-based Nano zinc application in barley cultivation offers a promising approach to enhance crop productivity, stress tolerance, and nutritional quality. Research has shown that Nano zinc positively impacts various aspects of barley growth, including root and shoot development, photosynthetic efficiency, and antioxidantdefenses. By improving nutrient uptake, reducing oxidative stress, and regulating hormone levels, Nano zinc enhances barley's ability to withstand environmental stresses and achieve higher yields.Despite these benefits, challenges such as environmental risks, variability in nanoparticle formulations, and gaps in understanding Nano zinc's behavior in soil-plant systems need addressing for safe and effective agricultural use. Moving forward, further research should prioritize optimizing Nano zinc formulations, dosage, and application methods. Integrating Nano zinc with other agricultural practices could maximize its benefits while minimizing potential drawbacks.

Overall, Nano zinc represents a promising and sustainable solution for combating micronutrient deficiencies and enhancing barley production in diverse agricultural settings. This approach holds significant potential to contribute to global food security and agricultural sustainability in the future.

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