UNVEILING THE POTENTIAL OF NANOPARTICLES INBARLEY FARMING

ABSTRACT

Barley continues to stand out as an important food source for human beings all over the world. It remains significant to manufacturing (industrial applications), especially in the malting and brewing sectors. This contributes to its promotion as a commercial crop through practices such as contract farming in Punjab, Rajasthan, and Haryana. Nanoparticle-based delivery mechanisms are high-end tools for enhancing zinc efficiency in barley crops.These involve coating and stabilizing zinc ions in nanoscale materials such as nanoparticles, nanotubes, or nanocarriers thus improving bioavailability and uptake besides abolishing soil solubility and mobility challenges. In conclusion, nano zinc is a sustainable way of addressing micronutrient deficiencies while promoting barley production under diverse agricultural conditions.This method has huge potential to improve future global food security and agricultural sustainability.

Keywords: *Hordeumvulgare*,Seedpriming,Nano zinc, Nutrient uptake, Abiotic stress, nanoparticles, agricultural sustainability, food production, nutrition.

1.INTRODUCTION

Barley is scientifically known as *Hordeum vulgare* and commonly referred to as "jau" in India. Barley has hardly played a significant role in global production throughout human history. Thus, barley comes fourth among cereal crops currently. This ranks globally at number four with a production of 155 million tons in 2022 after maize, wheat, and rice which make up about 12% of total cereal output. (Verma et al., 2022). Barley production thrives in different conditions including the tropical and temperate regions[51-54]. In India, it is majorly cultivated in states such as Rajasthan, Uttar Pradesh, and Madhya Pradesh. (Shekhawat et al., 2022). The grain has gained a lot of attention for its ability to survive in harsh conditions like drought, excessive heat, and frost (Newton et al., 2011; Wang et al., 2018). Barley is categorized into two genotypes which are two-rowed and six-rowed varieties that have different functions.Since the six-rowed barley is high in protein, it is utilized as animal feed, while the two-row one is traditionally used for malting in Europe, Australia, and south America. (Ozturk et al., 2023; Horsley et al., 2009). In agriculture, barley has a wide range of applications. 70% of the global production of barley is used as animal feed, with the remaining supporting beer and whisky production, and for different culinary purposes (Edney,1996). In addition, this crop is excellent for pasture, green manure, and as a monoculture, thus reflective of the multifarious value of this crop in farming systems. (Steinbach, 1997). The malting process, starting from steeping and germination to drying and storage, enhances the utility of barley by rendering it further processable into malt for brewing and distillation purposes. (Patel et al., 2019). All byproducts from the malting and brewing industries can be used to manufacture feed and non-feed products, that aid to tackle waste management practices. (Karlovic et al., 2020). Further ongoing research is therefore done in investigating the potential of barley in producing modified starches and cereals of high nutritional value, such as high protein or specialized starch compositions that can supply the nutritional fiber, vitamin and protein requirement. (Jadhav et al., 1998; Zohoori, 2020). Thus, barley remains to play a significant part in global agriculture, in food production, and human nutrition by proving its worth across various sectors.

2. SIGNIFICANT ADVERSE EFFECTS OF BARLEY PRODUCTION

The poor environment is one of the major challenges to crop production and acts through variousmeans on the growth of barley. The main challenges include drought, salinity, micro and macronutrient deficiency. All these factors lead to a reduction in yield and quality, the effect being more on the six-rowed used for malting because of its low carbohydrate content in the endosperm and high husk ratio, is more accentuated due to inappropriate irrigation and fertilizer application and restricted sowing of malt varieties. (Hajiboland, 2012). However, barley being an important crop in industrial uses, too ensures that with contract farming efforts in states like Punjab, Haryana, rajasthan the crop will ceratainly come up as a commercial crop. (Kumar et al., 2014). However, the adaptability of barley plants to environmental challenges, including drought, has been studied through genetic variation and the development of drought-tolerant genotypes (Bukhari et al., 2019; Serraj et al., 2011). The salinity, which is abundant in semi-arid and arid locations, as well as coastal areas with low-quality irrigation water, serves as another important barrier to barley production, hindering germination and early seedling stages (Pulido-Bosch et al., 2018; Fan et al., 2014). Barley's response to salt stress is driven by ionic responses rather than osmotic stress (Mahlooji et al., 2018). To counteract these challenges, potassium nitrate (KNO3) is applied to ameliorate oxidative stress and maintain favorable physiological features such as reduced malondialdehyde (MDA) content and altered K+/Na+ concentrations in leaves (Ahmad et al., 2022; Sofy et al., 2022) (Fig.1).

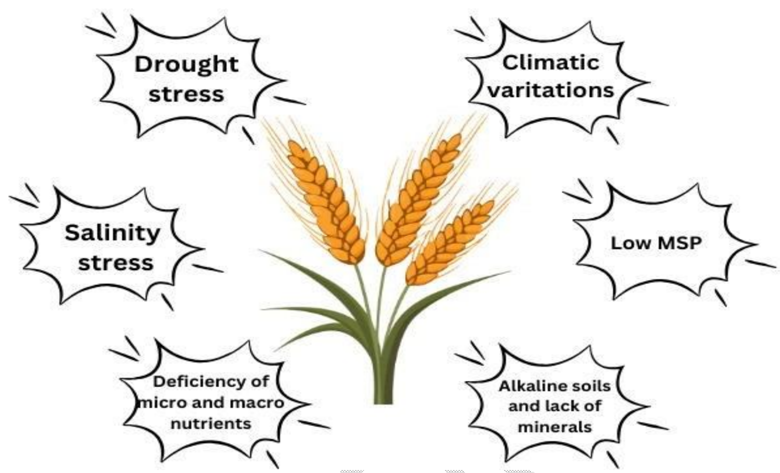

Fig.1. Significantadverseeffects on barley Production

3. SEED PRIMING IN BARLEY

Successful seed germination is essential in agriculture and horticulture (Kulkarni et al., 2011). Improper germination may result in erratic growth of seedlings and significant financial losses (Bisbis et al., 2018). Seed priming has become more prevalent as a means of rejuvenating seeds and enhancing yield from agriculture (Marthandan et al., 2020), notably in commercial applications and seed banks aiming to boost germplasm preservation (Farooq et al., 2019; Sershen and Hay, 2021). Primed seeds are hydrated and dried to stimulate metabolic activities, stimulation of enzymes, and antioxidant defenses, resulting in faster and more uniform germination over unprimed seeds (Jisha et al., 2013; Paul et al., 2022). There are several priming methods hydropriming, halopriming, 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 the potential to revolutionize 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).

Zinc oxide nanoparticles (ZnO NPs) are a type of Zn carriers that help in delivery to roots and improving the uptake as well as translocation with barley and other crops. (Eichert et al., 2011). This subsequently facilitated the stabilization, dispersion in applied soil, and interaction with plant roots ensuring more absorption of zinc into biomass leading to a boosted crop yield by chitosan or humic acid functionalization(Rizwan et al., 2019; Khan et al., 2019).

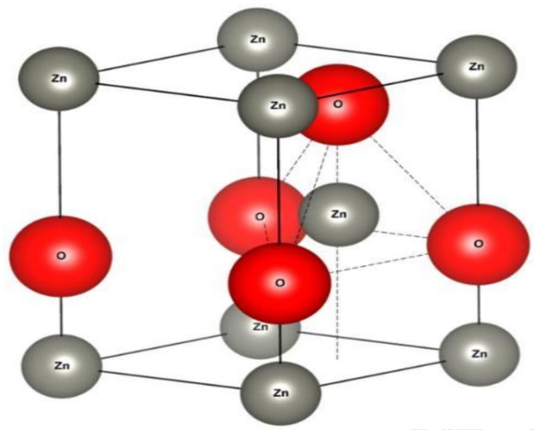

Fig. 2 SchematicillustrationofthewurtziteZnOstructure (Ding*etal.,*2008)

3.2 ImportanceofZincinBarleyGrowthand Development

Zinc Importance in Barley Growth and Development Zinc is important for barley growth, it is a co-factor to help enzymes that are necessary during photosynthesis and respiration as well as nutrient synthesis. (Marschner, 2012). This mineral controls the level of hormones in a living organism, promoting the elongation of cells in them, their roots, and the flowering of the seeds. (Alloway, 2008).The deficit is sure to lead to an inability to synthesize the DNA, divide the cells, or provide the membrane's integrity, decreasing stress resistance and overall vitality. (Cakmak, 2008). Structurally, zinc holds the integrity of the cell's wall and the stability of the membranes and transportation of ions, which is necessary for taking the diet from the outside and the ability to survive all the dangerous environmental influences.(Broadley et al., 2007). Chlorosis is a deficiency of chlorophyll pigmentation which is essential for photosynthesis, thus without it the plant will not be able to conduct the basic exchange of substances. A lack of zinc is also discovered in a worryingly low tillering and maturation process, which proves that the barley is formed by unhealthy seeds in need of being nourished. (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	➢ Required in DNA synthesis,celldivision,and membraneintegrity,thus increasing vigour in plants and their tolerances of stresses.	Cakmak, 2008
StructuralIntegrity	➢ Building block of proteins/complexes involved in cell wallsynthesis, stability of membranes, and transport of ions.	Broadleyetal., 2007
SymptomsofDeficiency	➢ Barley plants grow with characteristic symptoms of zinc deficiency, developing chlorosis, reduced tillering and delayed maturity.	Marschner,2012

Table.1ZincinBarleyGrowthandDevelopment

3.3 EffectsofNanoZinconBarleyGrowth Parameters

Nano zinc has a positive effect on the development of barley, contributing to increased quantity and better quality of the yield. This research showed that nano zinc aided in the growth of shoots, increased the amount of plant material, and enhanced photosynthesis. (Shahbaz et al., 2020; Rehman *et al*., 2019). Barley treated with Nano zinc has longer roots with more surface area and volume, which helps the plant take in nutrients and water better (Shahbaz *et al*., 2020). It also provides an extension of shoots, expanding the leaf area and enhancing general strength and features of growth in the plants. (Rehman *et al*., 2019).Nano-sized zinc improved the production of chlorophyll, the rate of photosynthesis, and the absorption of nutrients 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).Nano-sized zinc influences the activity of genes that control growth and response to stress, making barley more resistant to living and non-living threats(Rehman *et al*., 2019; Ghori *et al*., 2019).This stress-associated gene control helps the barely plants to strengthen themselves and survive in an unfavorable environment. However, nano-sized zinc is a promising way to increase the yield and hardiness of the barley crop. (Table 2).

Aspect	EffectsofNanoZincon Barley Plants	References
Growth Parameters	➢ Distinctly promotes rootandshootgrowth. ➢ Increasesbiomassaccumulation. ➢ Boosts photosynthetic efficiency.	Shahbaz*etal.,*2020;Rehman *et al.,* 2019
MorphologicalAttributes	➢ Increases root length, surface area, and volume. ➢ Promotesshootelongation andleafarea expansion.	Shahbazetal*.,*2020;Rehman *et al.,* 2019
PhysiologicalProcesses	➢ Enhanceschlorophyllsynthesisand photosynthetic rate. ➢ Improvesnutrientassimilation ➢ Alleviatesoxidativestress.	Ghorieta*l.,*2019;Shahbaz*et al.,*2020;Rehman*etal.,*2019

Table.2NanoZinconBarleyGrowthParameters

3.4. PhysiologicalandBiochemicalResponses ofBarleytoNanoZinc

Nano zinc improves the growth and quality of barley by enhancing the development of roots and shoots, increasing the amount of biomass produced, and improving the efficiency of photosynthesis. (Shahbaz et al., 2020; Rehman et al., 2019).It helps to increase the length and surface area of roots, as well as the uptake of nutrients, while also promoting the growth of shoots and the capacity for tillering. (Shahbaz *et al*., 2020; Rehman et al., 2019).Nano zinc also increases the production of chlorophyll, the rate of photosynthesis, and the activity of antioxidant enzymes, which makes barley more resistant to environmental stresses such as drought and saline soils. (Ghori et al., 2019; Shahbaz et al., 2020).In addition, it regulates the expression of genes to improve tolerance to stress and overall plant health. (Rehman *et al*., 2019; Ghori et al., 2019). Therefore,the application of nano zinc is beneficial for increasing barley productivity in 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

Using nano zinc in barley can help it grow better, produce more, and handle stress better. However, some problems need to be dealt with before it can be used safely and effectively in farming.One massive concern is how releasing nanoparticles into the environment could harm soil and water ecosystems.There's a chance that these particles could stick around for a long time and build up in non-target animals, which could be toxic for them. (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 (Dimkpaet 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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