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Zinc and Potassium nanoparticles as a seed priming agent to mitigate Drought Stress in Wheat (*Triticum aestivum* L.)

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ABSTRACT

This study examined how well wheat (*Triticum aestivum* L.) variety (DBW 71) responded to drought stress using a unique zinc and potassium nanoparticles (Zn-K NP) seed priming approach. Traditional nutri-priming ($ZnSO_4$ + K_2SO_4) and hydropriming controls were greatly surpassed by nano-priming with zinc and potassium nanoparticles at 50 ppm concentration under both well-watered and drought-stressed (40–45% field capacity) conditions. Zinc and potassium nanoparticles priming significantly improved germination percentage, coleoptile length, fresh weight of seedlings, dry weight of seedlings and seedling vigor index. According to the results the ability of nano-primed seeds to induce drought tolerance at crucial early germinative stage is highlighted by the fact that they demonstrated improved resilience under drought stress, sustaining noticeably higher growth parameters than other treatments. According to the study's findings, (Zn-KNP) seed priming is a very successful and environmentally friendly agrotechnology that enhances establishment and early growth while protecting wheat output from growing water scarcity.

Key words: *Zinc and potassium nanoparticles, Seed germination, Wheat (Triticum aestivum L.), Drought stress and nano-priming*

Introduction

Wheat (*Triticum* spp.) is an important cereal crop that belongs to the Family Poaceae, and Genus Triticum. *Triticum aestivum* L., or common wheat, is the most extensively grown of the many species and produces more than 90% of the world's wheat. In terms of global production and area covered, wheat is one of the most significant staple crops and ranks second only to rice. India is the world's second largest producers, producing 113.29 million tonnes followed by the European Union and Russia, with a consistent worldwide wheat output of 805.3 million tonnes in the 2023–2024 seasons (FAO, 2024). In India an average yield of 3,559 kilo per hectare, wheat was grown on 31.83 million hectares of land. The largest wheat-producing state in India is Uttar Pradesh, which produced 35.34 million tonnes of wheat overall in the 2023–24 crop year followed by Madhya Pradesh and Punjab being India's second and third-largest wheat-producing states, respectively (India STAT 2025).

Global output has remained stable despite regional variations brought on by weather patterns, geopolitical unrest, and evolving farming methods. As a major source of calories and protein, wheat continues to play a crucial role in ensuring food security, particularly in underdeveloped nations (Gupta *et al.*, 2023). In arid and semi-arid environments, where there is limited water availability for cultivation, abiotic stressors are the primary factor limiting output (Lehari *et al*., 2019; Bhandari *et al*., 2021). According to trends in global climate change, the world is witnessing a long-term shift in temperature and precipitation patterns, as well as environmental catastrophes such biotic and abiotic stressors, sea level rise, and glacier cap melting. Due to global climate change, one of the main abiotic pressures that farmers worldwide are dealing with is drought stress (Mansour *et al*., 2020).

Seed germination and early seedling growth in many crops are the most sensitive stages to drought stress and water deficit that may delay the onset and reduce the rate of uniformity of germination, leading to poor crop growth and yield (Demir *et al*., 2006). Seed priming is a pre-sowing strategy for influencing seedling development by modulating pre-germination metabolic activity prior to emergence of the radicle and generally enhances germination rate and plant performance (Taylor and Harman, 1990). It improves seed performance by rapid and uniform germination, normal and vigorous seedlings, which resulted in faster and better germination and emergence of different crops in normal and stress conditions (Powell *et al*., 2000; Cantliffe, 2003; Ashraf and Foolad, 2005; Carbineau and Come, 2006; Jisha *et al*., 2013). Seed priming has been proved to be an effective method in imparting stress tolerance to plants (Van Hulten *et al*., 2006). Primed seeds usually exhibit an increased germination rate, uniform germination with lower time and greater germination percentage and these attributes have practical agronomic implications especially under adverse growth conditions (Barsa *et al*., 2005). Therefore, seed industries need to find suitable priming agent(s) with strong emphasis for increasing the tolerance of plants under abiotic stress conditions. Seed priming is a rapid and cost-effective technology which can be adopted by farmers without any complication to enhance the germination and seedling growth of wheat under drought condition. The previous study demonstrated the potential of ZnO-NPs synthesized from *Lantana camara* leaf extract to enhance seedling growth, offering agricultural applications for improved seed germination and crop improvement (Agrawal *et al*., 2023). In lieu of the above information the current study was designed with following objective i) to investigate the influence of Zn and K nanoparticles as priming agent on seed germination and seedling growth in wheat variety DBW 71 under drought stress conditions.

Materials and Methods

Experimental Design and Plant Material

A petriplate experiment was conducted using wheat variety, DBW 71. The study employed a completely randomized design (CRD) with three replications. The treatments combined two factors: (i) seed priming and (ii) irrigation regime:

Table 1. Details of treatment

Treatment Code	Description
T1	Zn-K NPs primed seeds + drought stress
T2	Zn-K NPs primed seeds without drought
T3	$ZnSO_4$ + K_2SO_4 primed seeds + drought stress
T4	$ZnSO_4$ + K_2SO_4 primed seeds without drought
T5	Hydroprimed seeds + drought stress
T6	Hydroprimed seeds without drought

Seed Priming Protocol

Seeds were surface sterilized with 1% NaOCl. For priming, seeds were immersed in their respective solutions (1:5 w/v ratio) for 12 hours at 25±2 °C with continuous aeration. Post-soaking, seeds were rinsed and air-dried to their original moisture content (~10%) and stored at 4°C until sowing.

Drought Stress Imposition

By water hold for 7 days as compared to control

Data were recorded for

Germination (%)
Coleoptile length
Fresh weight
Dry weight
Seed Vigor Index: Germination % × (Shoot length + Root length)

Results and Discussion

The imposition of drought stress severely inhibited the germination and early seedling growth of wheat variety (DBW 71), confirming its status as a major constraint to wheat establishment (Hussain *et al*., 2019). The hydro primed control under drought (T5) exhibited significant reductions in all measured parameters compared to the well-watered control (T6), with a 26% decrease in germination percentage, a 29% decrease in speed of germination, a 51% decrease in seed vigour index, and a 28% decrease in coleoptile length (Figure 3). This aligns with the established understanding that water deficit disrupts imbibition, critical metabolic processes, and cell elongation, which are essential for radicle emergence and coleoptile growth (Farooq *et al*., 2009).

Fig. 1. Emergences of seedlings on different treatments for DBW-71 wheat genotype

However, seed priming with zinc and potassium significantly mitigated these adverse effects. Under drought stress, both conventional salt priming ($ZnSO_4 + K_2SO_4$, T3) and nano-chelate priming (Zn-K NP, T1) improved performance compared to the stressed hydroprimed control (T5). Crucially, the nano-chelate form (Zn-K NP) proved superior to conventional salts. Under drought, T1 resulted in a higher germination percentage (81.3% vs. 74% in T3), faster germination (12.4 vs. 10.6 seeds/day), a greater vigour index (1425 vs. 1135), and a longer coleoptile (3.3 cm vs. 3.0 cm).

This enhanced efficacy of nano-priming is likely due to the greater bioavailability and uptake efficiency of nano-scale nutrients (Rai *et al*., 2018). The zinc and potassium nanoparticles more effectively pre-load the embryo with essential ions, providing a ready source to kick-start metabolic machinery and antioxidant defense systems upon imbibition, even under water deficit (Tarafdar *et al*., 2014). The significantly superior coleoptile length observed in T1 seedlings suggests a more efficient stimulation of hydrolytic enzymes and auxin-mediated growth, which are crucial for establishing a vigorous stand under suboptimal conditions (Cakmak, 2000). The role of potassium in maintaining turgor pressure and supporting enzymatic processes likely synergized with zinc's role as a cofactor for critical enzymes, explaining the combined zinc and potassium nanoparticles success (Ahmed *et al*., 2024).

Notably, the performance of the Zn-K NPs under drought stress (T1) was not only better than the conventional prime under drought (T3) but also surpassed the performance of the conventional prime under well-watered conditions (T4) in terms of Germination Percentage and Speed of Germination. This underscores the profound impact of nano-priming in not just ameliorating stress but actively enhancing physiological performance to levels exceeding those achieved by conventional methods under optimal water availability.

Consequently, zinc and potassium nano particles

Table 2. Wheat genotype selected for morphological characterization under drought stress condition

Genotype	Pedigree	Origin	Grown	Features
DBW-71	M C306 /RAJ 1482/ /HUW 468	ICAR-IARI, Regional Station, Karnal	NWPZ	High yield, rust resistant, timely sown conditions

nano-priming emerges as a highly effective strategy to enhance drought tolerance at the critical germination stage. By improving stand establishment, vigour, and early growth, this technology has the potential to significantly reduce yield losses attributed to drought stress (Daryanto *et al.*, 2016), contributing to greater food security in the face of climate change.

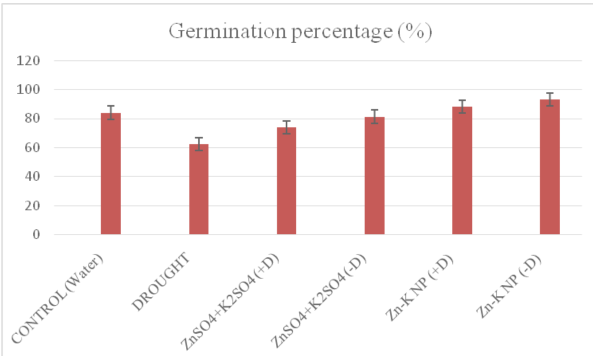

Fig. 2. Impact of zinc and potassium nanoparticles on Germination percentage (%) under different priming treatments

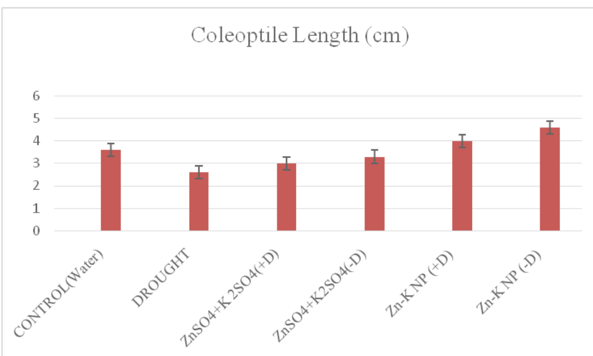

Fig. 3. Impact of zinc and potassium nanoparticles on Coleoptile Length (cm) under different priming treatments

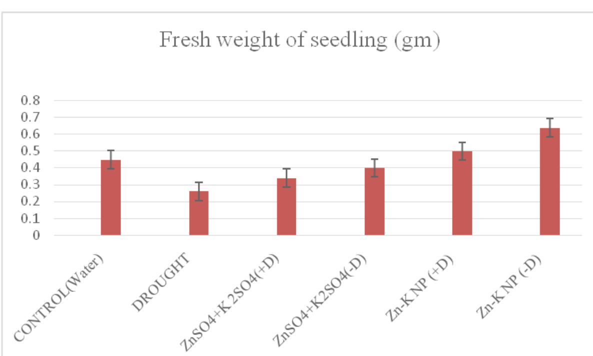

Fig. 4. Impact of zinc and potassium nanoparticles on Fresh weight of seedling (gm) under different priming treatments

The data indicates notable variation across treatments for the measured parameter in the DBW71 wheat genotype. Under control (water) conditions, the value was 0.45, representing a baseline status in optimal hydration without stress or supplementation. Drought stress significantly reduced this value to 0.26, highlighting the detrimental impact of water deficit on physiological or biochemical processes linked to this parameter. This reduction aligns with typical drought-induced impairment often observed in wheat, which may reflect compromised enzymatic activity, metabolic flux, or structural integrity under stress.

Application of conventional zinc sulfate and potassium sulfate ($ZnSO_4$ + K_2SO_4) supplementation under drought improved the value to 0.34, indicating partial mitigation of the negative effects of drought. The nutrient supplementation likely facilitated better osmotic balance or antioxidative de-

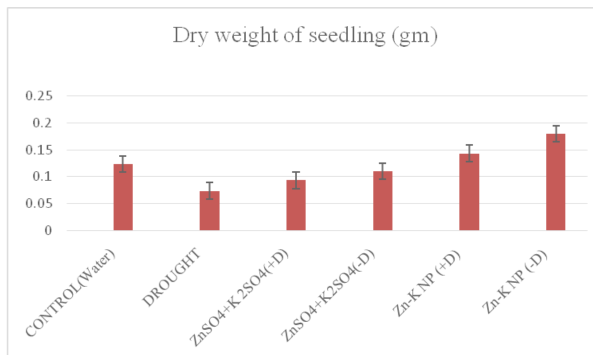

Fig. 5. Impact of zinc and potassium nanoparticles on fresh weight of seedling (gm) under different priming treatments

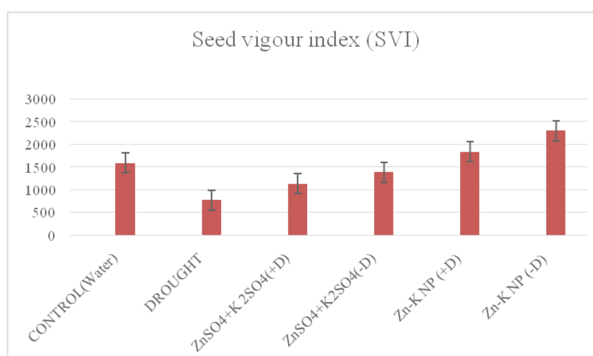

Fig. 6. Impact of zinc and potassium nanoparticles on seed vigour index under different priming treatments

fense, helping sustain the parameter closer to controlled levels. Under non-drought conditions, $ZnSO_4$ + K_2SO_4 treatment maintained a value of 0.40, marginally below the control, demonstrating no adverse impact and suggesting a beneficial nutrient provision.

Remarkably, the nano-formulated zinc and potassium nanoparticles treatments produced the highest values across conditions, with 0.50 under drought and 0.64 under non-drought scenarios. The superior performance of zinc and potassium nano particles suggests enhanced bioavailability and targeted delivery of zinc and potassium, improving the plant's resilience mechanisms against drought-induced stress. The increased value in both stressed and unstressed plants treated with zinc and potassium nano particle simplies a stimulation of metabolic or physiological pathways that favor growth, repair, or stress amelioration.

Overall, these findings underscore the potential of nano-enabled nutrient formulations such as zinc and potassium nano particlesto outperform conventional salts in sustaining or enhancing critical plant parameters under both normal and drought conditions in DBW71 wheat variety. This supports the growing evidence that nanotechnology-based agronomic inputs can contribute significantly to crop stress management and productivity enhancement.

Conclusion

In conclusion, the results unequivocally demonstrate that seed priming with zinc and potassium nanoparticles (Zn-K NP) is a highly effective agrotechnology to enhance drought tolerance in wheat. It significantly improves germination percentage, seedling vigor, and overall plant growth under both optimal and drought-stress conditions. The mechanism of action likely involves enhanced nutrient use efficiency, superior osmotic adjustment, and robust activation of the plant's antioxidant machinery.

The stark contrast between the performance of zinc and potassium nanoparticles and traditional $ZnSO_4$ + K_2SO_4 priming under drought highlights the superiority of the nano-scale delivery system. This study provides compelling evidence for adopting nano-priming as a sustainable strategy to safeguard wheat productivity in the face of increasing water scarcity due to climate change. For future perspectives, field-level validation of these findings and an in-depth molecular analysis of the stress pathways modulated by these nanoparticles are recommended.

Conflict of Interest- None

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