

Zinc Oxide Nanoparticles and magneto-priming in *Triticale*: Environmental Behaviour, Biological Responses, and Risk Implications

Mónica Montoya^{1,2*}, José Álvarez³, Marina de-Francisco¹ and Patricia Almendros^{1,2}

¹ Department of Chemistry and Food Technology, Agronomic, Food and Biosystems Engineering School, Universidad Politécnica de Madrid, 28040 Madrid, Spain

² Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), Universidad Politécnica de Madrid (UPM), 28040 Madrid, Spain

³ Department of Agroforestry Engineering, Agronomic, Food and Biosystems Engineering School, Universidad Politécnica de Madrid, 28040 Madrid, Spain

INTRODUCTION & AIM

- The environmental implications of nanoparticle-based agricultural inputs remain insufficiently understood, particularly for zinc oxide nanoparticles (ZnO-NPs), which are increasingly incorporated into fertilizers and agrochemicals.
- Ensuring their safe and sustainable use requires evaluating not only their potential phytotoxic effects on plants but also strategies capable of mitigating nanoparticle-induced stress.
- Magneto-priming represents a promising eco-friendly strategy capable of improving seed performance without chemical inputs, thereby contributing to green engineering, resource efficiency, and environmental sustainability.
- This study evaluates the effectiveness of magneto-priming in modulate triticale response to ZnO-NP exposure.
- The overarching objective is to evaluate how exposure pathways influence plant responses to ZnO-NPs and to identify sustainable mitigation strategies that support the safe use of nano-enabled agricultural inputs.

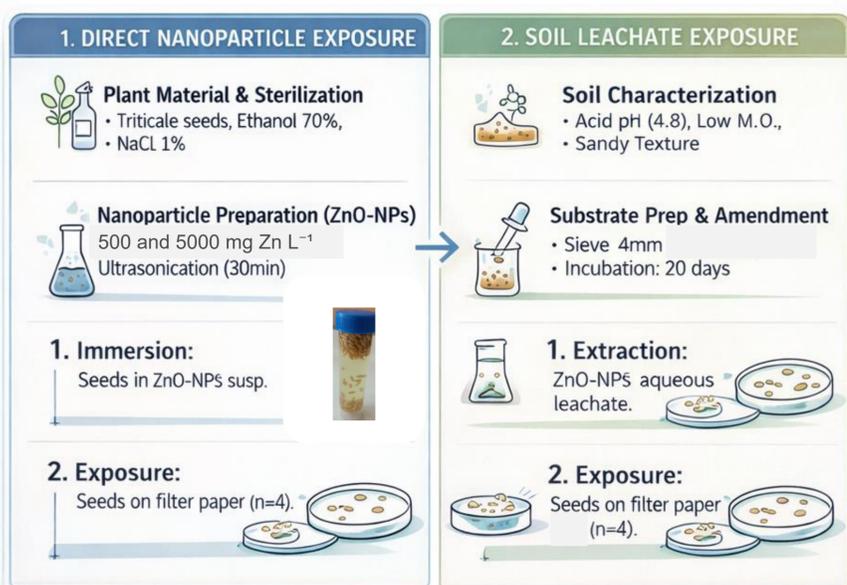
METHODS

MAGNETO-PRIMING OF SEEDS

- Each coil: 124 turns
- Electric current: 8 A
- Treatment duration: 10 hours
- Control seeds (MP-) were placed in an identical arrangement; however the coils were not connected to the power supply



GERMINATION ASSAYS



COMMON CULTIVATION & MEASUREMENT



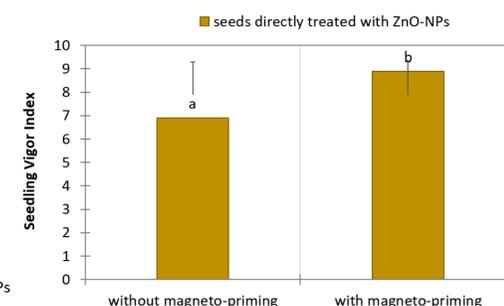
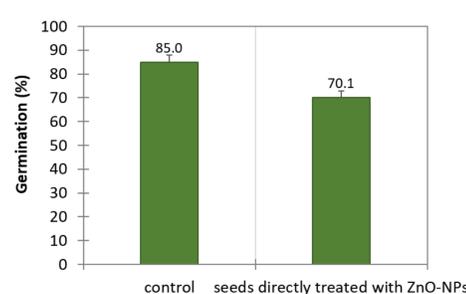
Environment:
7 days, 25°C, Dark

Variables Analyzed (Day 7)

- Germination % (Germination) (±2mm radicle),
 - Radicle/Shoot length, Total Roots/Seed
- Statistical ANOVA, t-test (p<0.05)

RESULTS & DISCUSSION

- Results showed an average 17.5 % reduction in germination in seeds directly treated with ZnO-NPs, likely due to ion release and the high reactivity of nanoparticle surfaces, indicating short-term phytotoxic potential under direct exposure.
- In contrast, MP treatment enhanced seedling vigour by 28.8%, improving shoot and root elongation and suggesting a capacity to alleviate early stress responses.
- Seeds exposed to soil leachates showed negligible effects, reflecting a limited mobility and bioavailability of ZnO-NPs within the soil matrix.



Under the conditions of this study, soil-applied ZnO-NPs showed a low environmental risk, consistent with recent reports indicating limited ecotoxicity of nanoparticle soil amendments at environmentally relevant concentrations (De-Francisco *et al.*, 2024; Sun *et al.*, 2023). In contrast, direct seed exposure induced localized phytotoxic effects, in agreement with findings that highlight the sensitivity of early plant stages to nanoparticle contact (Santás-Miguel *et al.*, 2023; Radhakrishnan *et al.*, 2019).

Magneto-priming (MP) modulated plant responses by enhancing root system development and alleviating nanoparticle-induced stress, supporting previous observations that priming treatments can improve stress tolerance and seedling vigor (Gutierrez *et al.*, 2024).

Overall, these findings contribute to the environmental risk assessment of nanomaterials and emphasize the need to carefully evaluate exposure routes and mitigation strategies to ensure the safe application of nano-enabled fertilizers.

CONCLUSIONS

- Direct seed exposure to ZnO-NPs caused short-term phytotoxicity, reducing germination and early seedling growth.
- Soil leachate exposure had negligible effects, indicating limited nanoparticle mobility and bioavailability. However, magneto-priming enhanced seedling vigour and root development, mitigating nanoparticle-induced stress.
- Findings emphasize the role of exposure pathways and support magneto-priming as a sustainable strategy for safe nano-enabled fertilizer use.

FUTURE WORK / REFERENCES

- Investigate nanoparticle transformations in soil systems and their influence on Zn bioavailability.
- Assess interactions between magneto-priming and nanoparticle exposure in other cereals beyond triticale.

De-Francisco *et al.* 2024 doi:10.3390/agronomy14050980
Santás-Miguel *et al.* 2023 doi:10.1016/j.envpol.2023.122222.
Sun *et al.* 2023 doi:10.1016/j.scitotenv.2022.159307.
Radhakrishnan *et al.* 2019. doi:10.1007/s12298-019-00699-9.
Gutierrez *et al.* 2024 doi:10.3390/seeds3010013.