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Correlation Between Zinc Oxide Nanoparticles and Hormonal-Antioxidant Responses in *Solanum lycopersicum* L. Under Cadmium Stress

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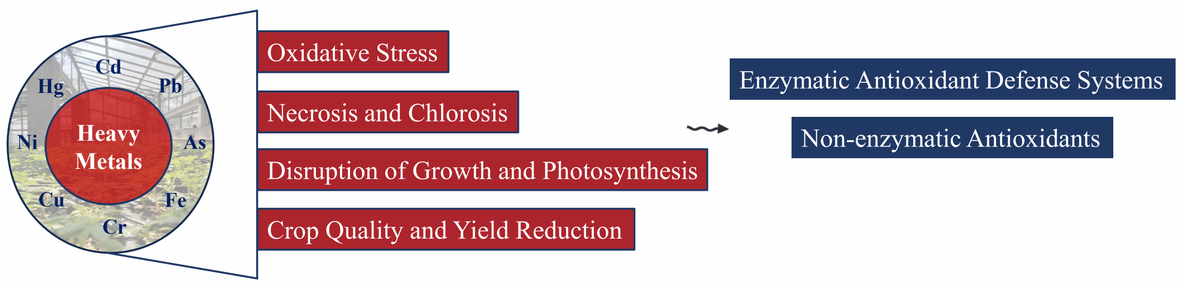
Abstract

Cadmium (Cd) stress induces oxidative damage in plants by generating excessive reactive oxygen species (ROS). This study aimed to evaluate the effects of zinc oxide nanoparticles (ZnO-NPs) on antioxidant defense, lipid peroxidation, and salicylic acid (SA) concentration in 30-day-old tomato leaves under Cd stress. Treatments included control, foliar application of 50 mg/L ZnO-NP solution, 1000 mg/kg soil $CdCl_2$ solution added to the soil, and the combination of ZnO-NP and $CdCl_2$ solutions. Leaf samples were collected at 24 and 96 hours. The presence of ZnO-NPs was confirmed using scanning electron microscopy (SEM). Catalase (CAT) activity, malondialdehyde (MDA) content were measured spectrophotometrically and SA concentration via HPLC. Cd exposure significantly increased CAT activity, MDA levels, and SA accumulation compared to control. Co-application of ZnO-NPs with Cd reduced MDA accumulation and modulated SA content compared to Cd treatment alone, indicating a protective effect of nanoparticles against oxidative stress. These findings suggest that ZnO-NPs can enhance plant resilience under heavy metal stress by partially alleviating lipid peroxidation and regulating antioxidant and hormonal responses.

Introduction



As an economically important crop, tomato (*Solanum lycopersicum* L.) is sensitive to Cd exposure and Cd stress significantly increases MDA (a product of membrane lipid peroxidation) accumulation and enhances the activities of SOD, peroxidase, and CAT in tomato seedlings. Moreover, the direct and indirect regulation of antioxidant and oxidative stress responses under abiotic stress have been closely associated with phytohormones such as abscisic acid (ABA) and salicylic acid (SA). Upregulation of ABA and SA biosynthetic and signaling genes has been linked to the enhancement of antioxidant defense systems and stress tolerance. Recently, ZnO-NPs have emerged as a promising strategy to mitigate Cd stress in plants. ZnO-NPs are proven to improve chlorophyll content, growth, and biomass in Cd-stressed tomato plants. In addition, ZnO-NPs were reported to enhance endogenous SA levels, contributing to reduced ROS accumulation and improved membrane stability. The present study investigates the effects of Cd stress on tomato plants and evaluates the role of ZnO-NPs in mitigating this stress by modulating SA concentration, CAT activity and MDA.

Materials and methods

1. Growth Under Greenhouse Conditions

2. SEM Imaging of ZnO NPs

3. CAT Activity — Monitoring the decomposition of hydrogen peroxide at 240 nm — Aebi (1984)

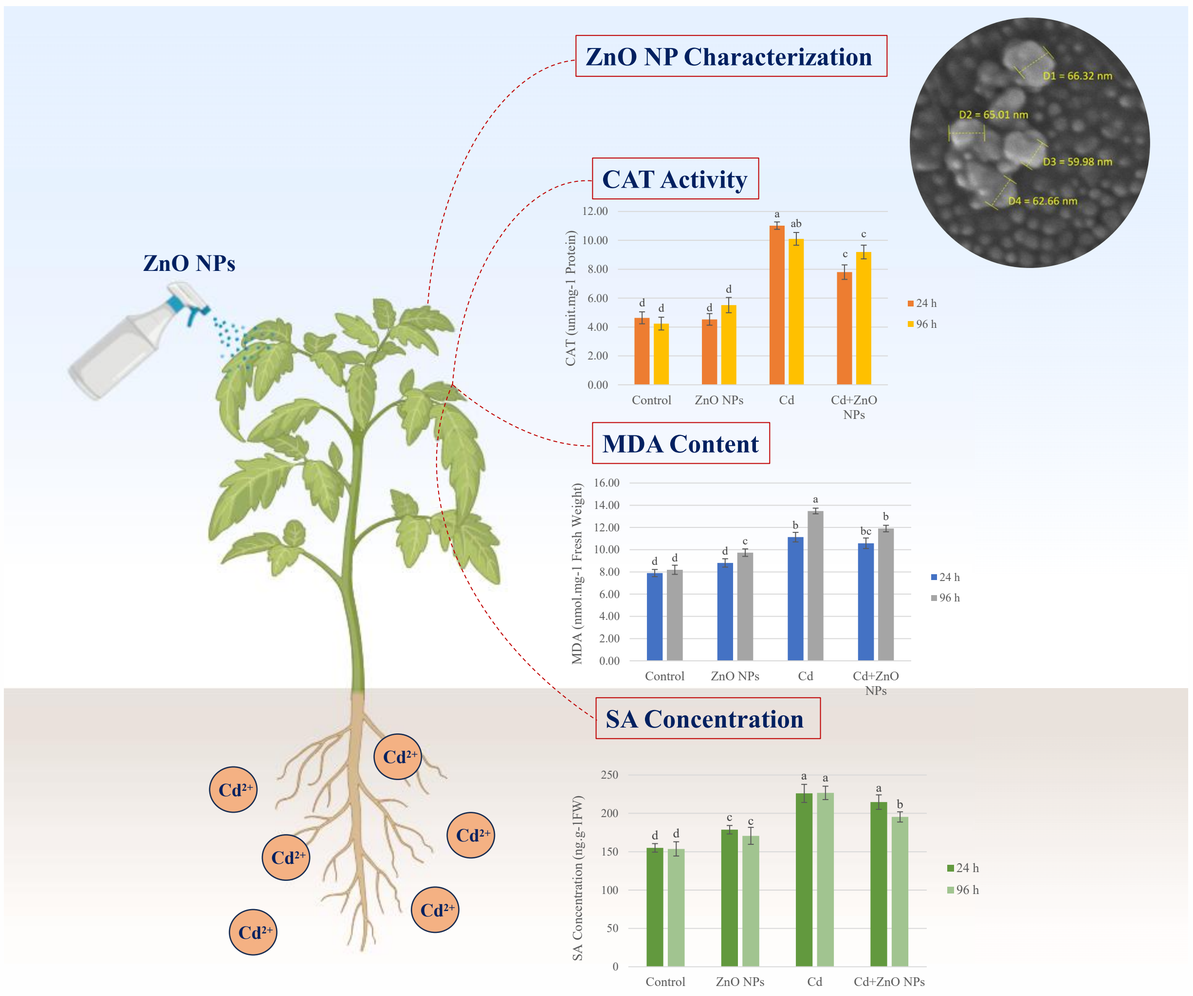
4. MDA Content — Measuring absorbance at 532 nm — Heath and Packer (1968)

5. Salicylic Acid Concentration

Using High-Performance Liquid Chromatography (HPLC)
Extraction using 80% methanol containing 0.1% acetic acid
Absorbance was detected at 303 nm

6. Statistical Analysis

Results and discussion



The results demonstrate the modulatory effects of ZnO nanoparticles on tomato responses to cadmium stress. CAT activity increased under Cd stress, but co-application with ZnO nanoparticles reduced it relative to Cd alone, suggesting a regulatory effect of nanoparticles on antioxidant responses. Similar effects of ZnO NPs have been reported by Sun et al. (2023) in tomatoes under Cd stress. Moreover, MDA content was highest under Cd exposure, while combined NP and Cd treatment mitigated MDA accumulation, indicating protection against membrane damage. This decrease aligns with the findings of Orfei et al. (2025) which confirmed the contribution of ZnO NPs to biotic stress tolerance in tomato seedlings. SA concentration was strongly affected by Cd, slightly increased by NPs alone, and decreased in the combined treatment over time, suggesting modulation of stress signaling pathways. Chen et al. (2025) observed similar fluctuations in SA concentration in response to nanobiochar treatment in rice seedlings under ciprofloxacin stress.

Overall, ZnO nanoparticles can enhance plant resilience under heavy metal stress by partially reducing oxidative damage and adjusting enzymatic and hormonal responses. Integration of SEM characterization with CAT, MDA, and SA measurements provides a comprehensive understanding of how nanoparticles influence plant physiochemical mechanisms under cadmium stress.

References

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