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# IMPACT OF ZINC OXIDE NANOPARTICLES UNDER LEAD TOXICITY ON CHILLI

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***Abstract*** *Capsicum annuum L., a widely cultivated and nutritionally dense crop, holds historical, culinary, and medical significance. The principal active ingredient, capsaicin, is known for its antioxidant, analgesic, and anti-inflammatory activities. Advances in nanotechnology, notably zinc oxide nanoparticles (ZnO-NPs), have shown promise in increasing crop yield. ZnO nanoparticles promote plant germination, root and shoot growth, nutrient uptake, and stress tolerance. However, large amounts might result in oxidative and genotoxic damage, needing careful treatment. Heavy metal contamination, particularly lead and cadmium, greatly reduces agricultural productivity and quality. ZnO-NPs reduce heavy metal toxicity by increasing antioxidant activity, photosynthesis, and metabolic activities. Studies on numerous crops, such as chili and tomatoes, highlight the advantages of optimal ZnO-NP application for sustainable agriculture. Despite promising findings, comprehending the precise mechanisms of ZnO-NPs and mitigating their phytotoxic effects remain essential for their widespread agricultural use.*

**Keywords:** *Capsicum annuum; culinary; medical; stress tolerance; metabolic activities*

## Introduction

*Capsicum annuum L* is a commercially significant and valuable crop throughout the world. Originally used as a medicinal herb by indigenous people, pepper has gradually become an important ingredient in the dishes of many cultures. The spread of cultivation can be attributed to explorers and traders introducing peppers to different regions, and adapting them to different climates and soils. Capsaicin is the major ingredient in chilies made from plants of the Capsicum genus, which is the most widely consumed chili in the world (Sharma et al., 2013). It is the heat-producing molecule in peppers and has been studied for its antioxidant, analgesic, and anti-inflammatory qualities. Today, peppers are grown in all countries and many varieties differ in size, color, spice, and taste. In recent years, the application of nanotechnology in agriculture has increased and it is a vital instrument in achieving the global objective of sustainable food production (Al Jabri et al., 2022; Mushtaq et al., 2024a). ZnO-NPs are developing as a viable tool in plant science, with huge implications for improved plant development and yield, one of the most important answers to the world's fast-rising population. However, depending on the plant and the dimensions and configuration of the ZnO-NPs used, it showed a variety of adverse effects on plants at large dosages and over extended periods. Much Work has been done to reduce the antagonistic effect of ZnO-NPs and short exposure times and doses are advantageous for plants. Moreover, functionalization is an excellent method for stabilizing NPs, decreasing ZnO-NPs' detrimental effects on plants while increasing their effectiveness. This review will show how ZnO-NPs are absorbed, distributed, and affect plant physiology (Mushtaq et al., 2024b; Thounaojam et al., 2021). Weather variations and other stresses can significantly affect the growth and productivity of plants and limit crop productivity. One of the biggest stresses is lead poisoning since it hinders agricultural output and growth. Lead, arsenic, and cadmium are some heavy metals that can contaminate soil through industrial, mining, and agricultural processes (Junaid and Gokce, 2024; Samanta and Roychoudhury, 2021). Lead, a heavy metal, poses a severe concern to food safety when contaminating crops. Chilli plants can absorb lead from contaminated soil via their roots. This uptake can occur passively or through active mechanisms that the plant uses to collect critical nutrients (Pal et al., 2018).

## Significance of Chilli

The red spicy pepper (*Capsicum annuum*), often known as chili, which has been exploited since ancient times as food, vegetables, flavoring components, and conventional therapies. Today, a wide range of sweet and pungent peppers are consumed in several ways around the world. Interestingly, *C. annuum* is the world's most important hot pepper in terms of commercial output, with many varieties. This review compares *C. annuum* to various Capsicum species in terms of plant agronomic properties, biochemical composition, capsaicin, and capsaicinoid concentrations, nutraceutical and therapeutic potential, and the effect of processing on fruit quality and main constituents. Chili has a high concentration of pigments (such as chlorophyll, anthocyanin, and lutein), which may provide health advantages (Hernández-Pérez et al., 2020).

A wide range of advantageous chemical substances are also present in it, such as minerals, vitamins, flavonoids, carotenoids, and capsaicinoids are all examples of this. The primary active ingredient giving these species their fiery flavor, capsaicin, has been demonstrated to have positive health effects. We present data on the effects of eating chili and capsaicinoids, especially capsaicin, on analgesic, antioxidant, urinary issues, body weight reduction, and potential anti-obesity advantages. Fruit preservation processing requirements that are specific to quality and chemical content are also met. To ascertain the exact mechanism of action and health benefits of regular consumption of capsaicinoids, more clinical research is necessary. Ascorbic acid ($r = 0.97$) and free sugars ($r = 0.80$) were related to total phenol concentrations in all accessions. The total phenol content of PI-633757, PI-387833, and PI-633754 was significantly higher (1.4, 1.3, and 1.3 mg $g^{-1}$ fruit) and ascorbic acid ($r = 0.97$) and free sugars ($r = 0.80$). PI-633757, PI-387833, and PI-633754 had significantly greater levels of total phenols (1.4, 1.3, and 1.3 mg $g^{-1}$ fruit) and ascorbic acid (1.6, 1.2, and 1.3 mg $g^{-1}$ fruit) compared to other evaluated accessions. PI-438622 had the greatest total capsaicinoid concentration (1.3 mg/g fruit), while Grif-9320 had the lowest (0.002 mg/g fruit). The considerable variability of these phytochemicals within and between Capsicum species suggests that these selected accessions may be useful as parents in hybridization efforts to develop fruits with value-added traits (Antonious et al., 2006)

## Historical and Medicinal significance of Red pepper

The red pepper (*Capsicum* spp.) has been cultivated on Earth for a very long time. The plant was used by Native Americans in South and Central America since 7000 B.C. and around 2000 years later it was cultivated in fields. The plant was taken to Europe after the Spanish made their first trips to the Americas, where it quickly spread to most tropical and subtropical areas as well as temperate ones. Pungent and non-pungent red pepper products rank among the most significant spices in the world by volume. Natural micronutrient antioxidants found in capsicum fruit, such as carotenoids and vitamins C and E, are highly concentrated and may have a role in the prevention and treatment of age-related and chronic illnesses. Historically, the fruit of the fiery hot pepper plant has been utilized in modern herbology and mainstream medicine. Capsaicin, the primary component in pungent Capsicum eliminates substance and other neuropeptides released by sensory nerve terminals. Capsaicin cream has been used in dermatological therapy and has shown effectiveness in reducing chronic pain caused by post-herpetic neuralgia, diabetic neuropathy, and other pain conditions (Palevitch and Craker, 1996). A sufficient comprehension of the molecular, physiological, and biochemical mechanisms of nanoparticles in plants encourages better plant growth and development (Siddiqui et al., 2015)

## Role of nanoparticles in enhancing plant growth

The structures with dimensions in the nm range are the most fundamental kind of nanoparticles. Atoms joined together with a radius of less than 100 nm are called nanoparticles. Since nanoparticles are tiny, highly soluble, and have excellent penetration, they are frequently used in a range of dosage forms. Numerous techniques, such as emulsion-solvent evaporation, double emulsion and evaporation, salting out, emulsion diffusion, solvent displacement/precipitation, polymerization, and coacervation/ionic gelation, can be used to prepare nanoparticles. In micro-wiring, nanoparticles can be used for gene transport, internalization, vaccination administration, and cell targeting. Orthopedic implants and cancer treatment are two medical uses for nanoparticles (Kumari, 2018). Significant within-species genetic variability in zinc composition is being employed in biofortification to alleviate dietary zinc deficits in humans. Surprisingly, a meta-analysis of information gathered from a comprehensive literature review suggests that evolutionary processes with impacts that go beyond the level of families could account for a small percentage of the genetic diversity in shoot zinc concentration. The brassicaceous Zn hyperaccumulators Thlaspi caerulescens and Arabidopsis halleri have recently undergone extensive morphological, physiological, pharmacological, genetic, and molecular characterizations that have yielded amazing insights into plants' evolutionary ability to adapt to high soil Zn concentrations (Broadley et al., 2007).

## ZnO Nanoparticles: Properties, Applications, and Synthesis Methods

At ambient temperature, the energy gap of zinc oxide (ZnO) nanoparticles is 3.37 eV, making them a breadth gap semiconductor. Its highly valued characteristics include catalysis, electrical, optoelectronics, and photochemistry. For catalytic reaction processes, ZnO nanostructures are fantastic.

Different methods can be used to produce ZnO nanoparticles, including anodization, co-precipitation, electrophoretic deposition, precipitation, laser ablation, ultrasound, microwave-assisted combustion, hydrothermal techniques, electrochemical depositions, the sol-gel method, chemical vapor deposition, thermal decomposition, and combustion techniques (Altammar, 2023). There has been a lot of interest lately in the application of zinc oxide nanoparticles, or ZnO-NPs, in plants and agriculture. NPs have been shown to offer a wide range of advantages, and these amazing substances can be utilized in place of a variety of fertilizers, micronutrients, fungicides, and antibacterial agents. Abiotic stressors including heat, salt, and drought are lessened in part by crops. On the other hand, a range of toxicities, such as oxidative stress, cytotoxicity, genotoxicity, physiological abnormalities, and growth/yield reduction, have been linked to high concentrations of ZnO-NPs. The kind and dosage of nanomaterials, the techniques of treatment, the developmental stage, the genotype of the species, and environmental factors all influence whether the results are positive or negative. Until all of the various ways that ZnO-NPs and the plant interact are fully understood genome or epigenome develop, it becomes more difficult to employ these new resources to their full potential, replacing traditional growth promoters or protectors. This necessitates the development of adequate technologies to determine plant conditions and optimize nanomaterial treatment (Kumar et al., 2021). The ZnO nanoparticles had a substantial effect on root length, shoot length, seedling length, and germination rate. Seed germination increased with increasing concentrations, but the findings thereafter reduced (Afrayeem and Chaurasia, 2017)

**Effects of ZnO Nanoparticles on Chili Moisture Content**

The delicious chili had a lot of water on it, according to the results. The sample with 20 milligrams of ZnO-NPs grew the quickest. The stem and root lengths were 18.20 ± 1.30 cm and 22.36 ± 070 cm on average, respectively, while the moisture content was approximately 84.02% on average. On sweet pepper leaves sprayed with 10 mg of ZnO-NPs and pure water, the height and quantity of leaves were identical. 19.76 ± 2.03 and 19.8 ± 2.62 cm, respectively, are the average stem lengths. The average length of the root, however, varied much more (Thassana et al., 2018)

**Influence of ZnO Nanoparticles on Germination and Growth of Chilli**

Measurements were made of total flavonoids, total phenol content, condensed tannins, and 2,2-diphenyl-1-picrylhydrazyl's (DPPH) antioxidant ability. The results demonstrated that applying zinc oxide nanoparticles (ZnO-NPs) to the seeds boosted the germination rate within the first seven days. ZnO-NP suspensions at concentrations of 100, 200, and 500 ppm, increased the germination of seeds by 123.50%, 129.40%, and 94.17% after treatment. The morphological characteristics analyzed showed that ZnO-NP treatments had a significant ($p < 0.01$) effect on radicle length, but no appreciable effect on plumule development. ZnO-NP suspensions with concentrations of 100, 200, and 500 ppm exhibited phytotoxicity by preventing the development of seedling radicles (García-López et al., 2018). The results showed that 100 ppm ZnO-NPs applied topically produced the best results In terms of growth metrics, physiological aspects, yield qualities, yield, and tomato quality traits. The same treatment (100 ppm of ZnO-NPs) assisted in the maximum amount of nutritional absorption. Applying 75 ppm ZnO-NPs topically resulted in the best Zn recovery utilization efficiency. Applying 100 ppm ZnO-NPs by foliar spray resulted in the largest yield increase (200%) over control. MARDI Tomato-3 (MT3) outperformed MARDI Tomato-1 (MT1) in the comparison between the two types. Zinc oxide nanoparticles used topically proved to be more effective than conventional zinc fertilizer, as the results demonstrate. Therefore, it is possible to suggest foliar spraying glasshouse soil with 100 ppm ZnO-NPs to boost the quantity and quality of tomatoes (Ahmed et al., 2023).

**Impact of Heavy Metals on Plant Growth and Abiotic Stress**

Many heavy metals, including zinc, cadmium, chromium, mercury, lead, arsenic, and copper, are increasingly becoming major causes of abiotic stress in plants. Though they have certain good characteristics in plant biological activity, and their scarcity can induce anomalies in metabolic pathways, their over-accumulation has a much greater damaging effect on plants. They impair primary activities such as photosynthesis, electron transport chain, and seed germination. Their toxic effects can also have fatal repercussions in plants, such as mutation, and can even disrupt the balance of macro and micronutrients in the plants because they generate reactive oxygen species (ROS) and are the sole source of oxidative stress in plants (Das et al., 2022). Plant Pb toxicity results in oxidative stress, DNA damage, and protein breakdown. Collectively, these negative consequences reduce agricultural output and quality. The use of lead-rich paints and gasoline, as well as municipal trash, has led to significant environmental lead accumulation. Lead concentrations grow significantly in industrial regions, accumulating in the surface layers of soil and decreasing as depth increases (Mukherjeea et al.)

**Mitigation of Lead-Induced Stress in Tomato Seedlings**

Examining growth metrics, Photosynthesis pigments, protein content, activity of nitrate reductase, antioxidant enzymes, and other variables, this researcher sought to determine whether bio-synthesized ZnO NPs could mitigate lead-induced oxidative stress in tomato seedlings. Solanum lycopersicum seedlings were treated with either lead or biosynthesized ZnO NPs alone for one treatment (50 mg L−1). Biosynthesized ZnO-NPs dramatically improved tomato seedling germination rate, seedling vigor index, relative water content, chlorophyll content, protein, carbs, and nitrate reductase activity when employed either by itself or in combination with lead. Furthermore, the negative consequences of lead-induced stress were lessened by biosynthesized ZnO NPs because they Enhanced antioxidant stress markers, including superoxide dismutase, catalase, ascorbate peroxidase, and upregulated photosynthetic machinery. The results of this study indicate that biosynthesized ZnO-NPs improve tomato seedling development and lessen lead stress (Azim et al., 2022). The capacity of ZnO nanoparticles to alleviate Cd stress in chili plants was confirmed by a comparable rise in total carbohydrates, soluble proteins, free amino acids, and photosynthetic pigments, especially when treated with Cd+ZnO-NPs. Lastly, when exposed to high levels of Cd, a foliar spray containing 100 ppm ZnO-NPs may improve plant growth metrics (Irfan and Bhatti, 2023)

**Conclusion**

ZnO nanoparticles, or ZnO-NPs, have a great deal of promise for improving plant growth and reducing stress from environmental elements and heavy metals like cadmium (Cd) and lead (Pb). Research indicates that ZnO-NPs enhance antioxidant activity, nutrient absorption, root and shoot growth, and seed germination. Although they have benefits over conventional fertilizers, their efficacy varies depending on the plant species, concentration, and application technique. The necessity for cautious use is highlighted by the possibility of phytotoxicity from excessive quantities. Although ZnO-NPs present a promising way forward for sustainable agriculture, more study is required to fully comprehend their effects on plant physiology and optimize their use.

**References**

Afrayeem, S. M., and Chaurasia, A. (2017). Effect of zinc oxide nanoparticles on seed germination and seed vigour in chilli (Capsicum annuum L.). *Journal of Pharmacognosy and Phytochemistry* **6**, 1564-1566.

Ahmed, R., Uddin, M. K., Quddus, M. A., Samad, M. Y. A., Hossain, M. M., and Haque, A. N. A. (2023). Impact of foliar application of zinc and zinc oxide nanoparticles on growth, yield, nutrient uptake and quality of tomato. *Horticulturae* **9**, 162.

Al Jabri, H., Saleem, M. H., Rizwan, M., Hussain, I., Usman, K., and Alsafran, M. (2022). Zinc oxide nanoparticles and their biosynthesis: overview. *Life* **12**, 594.

Altammar, K. A. (2023). A review on nanoparticles: characteristics, synthesis, applications, and challenges. *Frontiers in Microbiology* **14**, 1155622.

Antonious, G. F., Kochhar, T. S., Jarret, R. L., and Snyder, J. C. (2006). Antioxidants in hot pepper: variation among accessions. *Journal of Environmental Science and Health, Part B* **41**, 1237-1243.

Azim, Z., Singh, N., Khare, S., Singh, A., Amist, N., Yadav, R. K., and Hussain, I. (2022). Potential role of biosynthesized zinc oxide nanoparticles in counteracting lead toxicity in Solanum lycopersicum L. *Plant Nano Biology* **2**, 100012.

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., and Lux, A. (2007). Zinc in plants. *New phytologist* **173**, 677-702.

Das, D., Mondal, B., Dey, A., Mridha, D., and Roychowdhury, T. (2022). Overview on the effects of heavy metals on the biological activities of leafy vegetables. *In* "Response of Field Crops to Abiotic Stress", pp. 67-78. CRC Press.

García-López, J. I., Zavala-García, F., Olivares-Sáenz, E., Lira-Saldívar, R. H., Díaz Barriga-Castro, E., Ruiz-Torres, N. A., Ramos-Cortez, E., Vázquez-Alvarado, R., and Niño-Medina, G. (2018). Zinc oxide nanoparticles boosts phenolic compounds and antioxidant activity of Capsicum annuum L. during germination. *Agronomy* **8**, 215.

Hernández-Pérez, T., Gómez-García, M. d. R., Valverde, M. E., and Paredes-López, O. (2020). Capsicum annuum (hot pepper): An ancient Latin-American crop with outstanding bioactive compounds and nutraceutical potential. A review. *Comprehensive Reviews in Food Science and Food Safety* **19**, 2972-2993.

Irfan, S. M., and Bhatti, K. H. (2023). Zinc Oxide Nanoparticles Mitigate Toxic Effects of Cadmium Heavy Metal in Chilli (Capsicum annuum L.). *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences* **60**, 477-487.

Junaid, M. D., and Gokce, A. F. (2024). Global agricultural losses and their causes. *Bulletin of Biological and Allied Sciences Research* **2024**, 66.

Kumar, A., Singh, I. K., Mishra, R., Singh, A., Ramawat, N., and Singh, A. (2021). The role of zinc oxide nanoparticles in plants: A critical appraisal. *Nanomaterial biointeractions at the cellular, organismal and system levels*, 249-267.

Kumari, B. (2018). A Review on Nanoparticles: Their Preparation method and applications. *Ind Res J Pharm Sci* **5**, 1420.

Mukherjeea, S., Agarwala, S., Chakrabortya, A., Mondala, S., Haquea, A., Balaa, D., Ghosha, A.,

Singha, S., and Talukdera, P. A comparative study on the effect of metal induced stress in two major vegetable crops of West Bengal, India– Brinjal (Solanum melongena) and Chili (Capsicum annuum).
Mushtaq, F., Akram, M. H., Usman, M., Mohsin, M., and Nawaz, M. S. (2024a). Global climate change and its influence on crop production. *Journal of Life and Social Sciences* **2024**, 27.
Mushtaq, R., Shafiq, M., Batool, A., Din, M. I., and Sami, A. (2024b). Investigate the impact of zinc oxide nanoparticles under lead toxicity on chilli (*Capsicum annuum* L). *Bulletin of Biological and Allied Sciences Research* **2024**, 90.
Pal, A. K., Chakraborty, A., and Sengupta, C. (2018). Differential effects of plant growth promoting rhizobacteria on chilli (Capsicum annuum L.) seedling under cadmium and lead stress. *Plant Science Today* **5**, 182-190.
Palevitch, D., and Craker, L. (1996). Nutritional and medical importance of red pepper (Capsicum spp.). *Journal of herbs, spices & medicinal plants* **3**, 55-83.

**Declaration**

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**Authors' Contribution**

**RM**: Originated the study idea, proposed the method for the research, and oversaw the entire research endeavor.

**MS**: He analyzed the data, made interpretation of the results and was involved in the preparation of the manuscript.

**AB**: Participated in the literature search, data gathering and review and writing of the manuscript.

**MIDIN**: With regard to the above analysis, she played the major role in data collection, contributed to data analysis and interpretation, and finalized the manuscript for overall ideas and contents.

**AS**: Assisted in the conception, data analysis and drafting of the manuscript so as to maintain cogency within the study.

**Conflict of Interest**

The authors state that there is no conflict of interests with regard to this study. There is no conflict of interest in any financial or personal manner concerning the development of this project, the gathering of data, the interpretation of the data, or the writing and publishing of this paper.

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All authenticated data have been included in the manuscript.

**Ethics approval and consent to participate**

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Samanta, S., and Roychoudhury, A. (2021). Heavy metal toxicity in plants: Physiological and molecular adaptations. *In* "Heavy Metal Toxicity in Plants", pp. 1-10. CRC Press.
Sharma, S. K., Vij, A. S., and Sharma, M. (2013). Mechanisms and clinical uses of capsaicin. *European journal of pharmacology* **720**, 55-62.
Siddiqui, M. H., Al-Whaibi, M. H., Firoz, M., and Al-Khaishany, M. Y. (2015). Role of nanoparticles in plants. *Nanotechnology and plant sciences: nanoparticles and their impact on plants*, 19-35.
Thassana, C., Phuengkum, N., Srikongrug, S., Petpaiboon, J., and Noenrimnong, W. (2018). The Effect of Zinc Oxide Nanoparticles on Growth of Sweet Chilli. *ASEAN Journal of Scientific and Technological Reports* **21**, 51-57.
Thounaojam, T. C., Meetei, T. T., Devi, Y. B., Panda, S. K., and Upadhyaya, H. (2021). Zinc oxide nanoparticles (ZnO-NPs): a promising nanoparticle in renovating plant science. *Acta Physiologiae Plantarum* **43**, 1-21.

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