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Zinc oxide Nanoparticle (ZnONPs) Seed Priming: A Sustainable Strategy for Enhancing *Zea Mays* Tolerance to Salt Stress

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ABSTRACT

Salt stress is a severe environmental problem that negatively impacts crop growth, development and yield. *Zea mays* (maize), a globally major grain crop, is especially vulnerable to salt. The desire to boost the germination and productivity of crops by nanotechnology has gained importance in the agriculture sector. Biological technique is the most recently developed way for creating nanoparticles since it is less complicated, environmentally friendly, and time-consuming than the other approaches. A viable, sustainable method for reducing salt-induced stress and enhancing plant resistance is zinc oxide nanoparticle (ZnONP) seed priming. When ZnONPs are used in seed priming, maize plants experience less oxidative stress and ion toxicity due to improved water uptake, nutritional assimilation and enzymatic antioxidant activities. Furthermore, ZnONPs improve the regulation of reactive oxygen species (ROS), stabilize cellular membranes and encourage effective ion homeostasis, all of which lead to increased salt tolerance. An effective method for enhancing crop resilience in saline environments is ZnONP seed priming, which combines nanotechnology with traditional crop management techniques. This review will focus on enhancing the tolerance of corn by ZnONPs seed priming under salt stress.

Keywords: Nanotechnology, ZnO nanoparticle, Seed priming, *Zea mays*, Salt stress, Sustainable agriculture

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Introduction

Plants in the wild are subject to a variety of biotic and abiotic stressors. The main abiotic factors that directly impede crop plant growth and development are soil salinity, water deficit, heavy metals and extremely high or low temperatures. Food demand is rising throughout time due to an overpopulation, and maize is becoming a more important crop to raise because of its high potential yield, high nutritional value, short growth period, and use in industry to make corn silk, corn sugar, and corn flask [1]. A major issue in agriculture, high salinity reduces the crop yields annually by harming plants through the osmotic effect, which lowers water intake and by allowing too many ions to enter the transpiration stream, which damages cells. The FAO report from 2021 states that salt affects over 833 million hectares of soil worldwide, or 8.7% of the planet. Plant water relationship, oxidative stress, carotenoid and chlorophyll pigments, general plant growth, seed germination, nutritional imbalance, and overall crop production are all negatively impacted by salinity in the soil [2].

The three main global staple cereals wheat, rice and maize are grown on approximately 200 million (M) hectares (rounded). More than 9,000 years ago, in southern Mexico or Meso America, they were domesticated. Maize has spread rapidly throughout the world and is currently the most widely produced staple cereal, with an annual production of over 1 billion metric tons Corn belongs to the grass family and is a monocotyledonous annual herb cereal crop. However, it is recognized as the "Queen of Cereals" [3]. Corn kernels comprise 61%–78% carbohydrate, 10% non-starch polysaccharides, 6%–12% protein, and 3%–6% lipids on a dry basis. Vitamin B-complex is also present. It contains vitamins C, A, and K, which are essential for the immune system and promote healthy thyroid function, as well as a reasonable amount of selenium and a substantial amount of beta carotene. Corn silk contains maizeric acid, fixed oils, resin, sugar, mucilage, salt, and fibers that are essential for human nutrition. Secondary metabolites of phytochemicals such as saponin, allantoin, sterol, stigmasterol, alkaloids, hordenine, and polyphenols are found in leaves, seeds, and corn silk [4].

There are new technologies like nanotechnology that have been developed to lessen the adverse impacts of environmental stress on crop plants. Modern agriculture can benefit from the use of nanotechnology in a number of ways, including increased sustainability, less pollution, plant disease prevention, food security and water efficiency. In this sense, nanoparticles (NPs) can support stress tolerance, fight nutrient shortages and raise crop output and quality [5]. The application of nanotechnology in agriculture is helping to achieve sustainability in the future. One of the newest, most economical and ecologically friendly methods for increasing crop yields under unfavorable soil and climate circumstances is seed priming with nano chemicals. This technique uses less input and makes better use of primary resources. Seed priming of ZnONPs effectively reduce the effects of salt on corn by increasing the antioxidant activity and photosynthetic activity [6].

Mechanism of ZnO Nanoparticles

Salt stress has a negative effect on maize development, yield, and physiological processes through osmotic stress, ion toxicity, oxidative stress, and nutritional imbalance. One promising nanomaterial to lessen the consequences of salt stress is zinc oxide nanoparticles. Excess reactive oxygen species (ROS) are produced by plants during salt stress, which causes oxidative damage. ZnONPs help scavenge ROS and protect cellular components by boosting the activity of antioxidant enzymes like peroxidase (POD), catalase (CAT), and superoxide dismutase (SOD). ZnONPs regulate ions. Salt stress decreases photosynthesis decreases chlorophyll concentration and decreases the efficiency of photosystem II (PSII). By promoting chlorophyll production, ZnONPs lessen this. Additionally, it aids in improving water retention and osmoregulation. It enhances nutrient intake and promotes root growth [7].

ZnO's function in plant development and growth

By producing an excessive accumulation of reactive oxygen species (ROS), abiotic stressors, especially salt, cause oxidative damage to plants. This damage affects membrane lipids and other cellular components, impairing cell structure and function. Zinc is one of the essential nutrients for the best possible growth of plants. Photosynthetic pigments are essential for development and control many biological functions, such as cell division, plant growth, and development [8]. Additionally, under abiotic stress, ZnONPs had a favorable impact on plant growth and yield. Triacylglycerol hydrolysis releases glycerol and fatty acids (FA) from the transformed sugar, which is the germination fuel for seeds that contain oil. Additionally, during seed germination, storage lipids release the energy source (FA) to create soluble carbohydrates and ATPs. It also involves in the regulation of reactive oxygen species. It enhances the nutrient uptake and water retention [9].

Seed Priming: A Promising Technique for Stress Tolerance

With minimal effort and money, seed priming treatments can mitigate the effects of salt. During priming, seeds are immersed in a variety of fluids with high osmotic potential. The seeds are consequently unable to absorb enough water for radicle protrusion, leaving them stranded in the lag phase [10]. To coordinate emergence and reduce the time between seed sowing and seedling emergence, seed priming has been used extensively. By starting a number of physiological and metabolic processes, seed priming is an easy and reasonably priced method that improves germination and seedling establishment. By controlling biological pathways and promoting the production of many stress-related genes and proteins, priming accelerates stress and cross tolerance. ZnONPs improve priming efficiency in this approach [11].

Challenges and Future Perspectives

There are potential advantages and disadvantages of using ZnONPs in seed priming. Although ZnONPs have demonstrated promise in improving crop resilience to environmental stressors and seed germination, a number of challenges need to be overcome to maximize their use in agriculture. It is important to understand these dual aspects for responsible nanotechnology application [12]. In organisms, nanoparticle accumulation can have harmful consequences. ZnONPs in treated wastewater increasing the likelihood of health problems from increased exposure to trace elements. Because nanoparticles can pass through biological membranes, they may cause nephrotoxicity and neurotoxicity, among other health problems. Despite of hazards, certain nanoparticles efficiently eliminate contaminants from soil, water and air, underscoring their dual function in environmental health [13]. ZnONPs' efficacy might differ greatly depending on their size, shape and concentration, making standardization for agricultural usage challenging [14]. More efficient farming methods may result from the development of customized ZnONP formulations that enhance nutrient uptake and stress tolerance. ZnONPs may perform better at reducing abiotic stress if combined with other nanomaterials or biotechnological techniques. Along with creating regulatory frameworks for their use, conducting comprehensive field experiments will be essential to determining the practicality of ZnONPs. Despite of these obstacles, ZnONPs still have a lot of potential for sustainable agriculture, which calls for more study and development to fully realize their advantages [15].

Conclusion

Nanotechnology has recently been marketed as a more economical, effective and ecologically friendly way to improve agriculture. ZnONPs have demonstrated enormous promise in the control of salinity in plants. Because of their antioxidant qualities, ZnONPs scavenge ROS and lessen oxidative damage brought on by abiotic stress. Additionally, they boost the activity of antioxidant enzymes, which helps plants have a robust defensive mechanism. ZnONPs also help to maintain cellular water balance, regulate osmotic pressure and lessen the impacts of abiotic stress. Stress tolerance is further enhanced by ZnONPs' regulation of plant hormone signaling pathways and other stress-responsive genes. Additionally, ZnONPs enhance nutrient availability and uptake, enhancing the general resilience and health of plants. Further study is required in the future to fully comprehend the mechanisms of action of ZnONPs in the treatment of abiotic stress.

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