Chapter 5
Nanoparticle-Mediated Approaches in Agriculture Addressing Abiotic Stress From Soil to Plant Cells

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ABSTRACT

NPs are increasingly prevalent in various fields including biology, pharmacology, cosmetics, and agriculture, promising diverse applications. However, their widespread use raises concerns about their environmental impact. Thus, it is imperative to comprehensively study how NPs affect plant physiology and metabolism, given that plants inevitably encounter NPs in soil and water. Understanding the mechanisms of NP entry, transport, and accumulation within plants is pivotal. Moreover, once internalized by plants, NPs can profoundly influence cellular metabolism and physiology.

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INTRODUCTION

The Utilize of tailored NPs in the industrial, agricultural, and medicinal sectors has significantly increased within the last 20 years (A. Singh, Rajput, et al., 2024; A. Singh, Rajput, Varshney, et al., 2023a; A. Singh, Sharma, et al., 2022a; Verma et al., 2022). Because they come in a wide variety of sizes and forms, engineered NPs have distinct characteristics from their naturally occurring counterparts (Chhipa & Joshi, 2016). With their widespread use, it is unavoidable for these NPs to enter the environment. Excess nanomaterials, whether directly introduced through agricultural practices or indirectly via industrial waste, present a significant risk of contaminating soil and water resources. Therefore, it is crucial to comprehend the effects of NPs on various plant species prior to their release into the environment. In the previous 20 years, the utilization of nanotechnology in agriculture has emerged as a highly effective approach to ensuring sustainable food security (Ram et al., 2023; A. Singh et al., 2021). Nanofertilizers, renowned for their exceptional nutrient utilization efficiency, have proven to be significantly more potent in enhancing crop yields (Alvarado et al., 2024; Zulfiqar et al., 2019a). Their precise delivery mechanisms allow for targeted application, reducing overall fertilizer usage while substantially increasing productivity. Similarly, the rise of biopesticides, characterized by their minimal active ingredient content yet remarkable efficacy, has garnered widespread adoption as they offer robust plant protection without causing adverse environmental effects (Kah, 2015). Moreover, the utilization of nanosensors holds promise in detecting microclimate fluctuations within agricultural settings (Pérez-de-Luque, 2017). This early warning system enables farmers to preemptively address biotic and abiotic stressors before they compromise crop yields. The advent of nanosensors has not only revolutionized precision farming and sustainable agriculture but has also elevated human intervention in maintaining soil and plant health (A. Singh, Rajput, et al., 2024). The escalating utilization of NPs is unmistakably linked to their accumulation in the environment. Moreover, various NPs employed across different sectors, including agriculture, permeate into the air, water, and soil through various pathways. Industrial contaminants often contaminate water bodies, posing a potential risk of NP pollution (Ashraf et al., 2021). Another significant NPs reservoir is soil, which either directly or indirectly absorbs NPs (Zhang et al., 2022). As the cornerstone of ecosystems, plants intimately interact with the air, water, and soil. According to several research any negative impacts of NPs on plants may eventually cause harm to humans and animals (Al-Busaidi & Jukes, 2015; Bondarenko et al., 2013; Fajardo et al., 2022; Gogos et al., 2012; Natasha et al., 2022). Thus, thorough examination of their impact on plants is imperative when extensively employing NPs in the natural environment. Furthermore, since NPs inherently influence plant growth and development, investigating their effects on soil microflora is crucial. Ultimately, any favorable or adverse influence on crop plants could significantly impact plant-microbe relationships.

Drought, salt, and heavy metals cause plant abiotic stress, which retards plant development and lowers crop output. Physiological processes have developed to protect plants from these challenges. Nanoparticles help plants cope with abiotic stressors (A. Singh, Margaryan, et al., 2024). Arid locations have lower agricultural yields and biomass due to environmental, meteorological, and other variables. Sun et al. treated maize with ZnO NPs and discovered that nanoparticles boost photosynthetic rate and chlorophyll content under drought stress (Sun et al., 2021). Plant nutrient imbalance and sluggish development result from improper salinity (Miao et al., 2020). Nanoparticles in agriculture can boost salt tolerance enzyme activity. ZnO NPs reduced cotton and wheat salt stress (Hussein & Abou-Baker, 2018). SiO2 NPs on cucumber leaves increased the elasticity and expansion of the cell wall during growth and increased the accumulation of nitrogen and phosphorus elements in the leaves by reducing leaching loss, which