Chapter 15
Revolutionizing Sustainable Agriculture With Nano-Priming Technology:
A Leap Towards Resilient and High-Yield Crops

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ABSTRACT

The development and growth of crops were impacted by climate change, leading to a decrease in crop production. The issue of food security can arise from a decline in agricultural output. Emerging from the confluence of nanotechnology with agriculture and materials science, the emerging discipline of nano priming enhances the effectiveness of priming agents by utilizing the distinct physicochemical characteristics of nanoparticles (NPs). By carefully dotting seeds or substrates with engineered nanomaterials, this method seeks to improve essential physiological processes or material qualities via nanoscale targeted interactions. To further reduce reliance on fertilizers and pesticides, nano-seed priming improved metabolic, biochemical, antioxidant, and phytohormone pathways; this, in turn, promoted abiotic and biotic stresses. An introduction to nanoparticles and their potential uses in environmentally friendly farming practices is given in this chapter.

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INTRODUCTION

Nano priming in agriculture revolutionizes seed treatment strategies by utilizing the advantageous surface area-to-volume ratio and customized surface chemistry of nanoparticles. Traditional farming methods also contribute to environmental pollution due to their reliance on pesticides and fertilizers (Rajput et al., 2018). Since 90% of the world's food crops start as seeds, seed is an essential component of long-term agricultural output and productivity (Shelar et al., 2023). A plant's life cycle begins with seed germination, and in certain ecosystems, such as rangeland and agricultural land, proper germination is essential to the survival and conservation of plant species (Manjaiah et al., 2018). Research has demonstrated that nanomaterials can enhance the germination process of seeds through various mechanisms. These include creating nanopores in the seed coat, introducing reactive oxygen species (ROS), enhancing enzyme activity at sites that break down starch, and introducing ROS to the seed coat itself. Plant hormones and reactive oxygen species (ROS) are two of many signalling molecules that control when seeds germinate. Reactive oxygen species (ROS) keep abscisic acid, auxins, gibberellins, and ethylene in check, and they regulate gene expression and phytohormone signalling (Nile et al., 2022).

Nanomaterials, and nanoparticles in particular, have the potential to improve crop protection (Scott et al., 2018). Several agricultural companies have taken an interest in this promising field of research, which has led to the incorporation of nanoparticles into various formulations (Chau et al., 2019). According to Acharya et al. (2020) and Rajput et al. (2021c), pest control, plant nutrition, and environmentally responsible production methods are all possible applications for nanopesticides and nanofertilizers.

Seed treatment with nanoagrochemicals is an effective way to modify seed metabolism and signalling pathways, which in turn affects germination and the beginning of the plant's life cycle (Shelar et al., 2023). Seeds treated with nanomaterials have several potential benefits, including storage protection, faster germination, better early growth, and much less pesticide and fertilizer usage (Shao et al., 2022). Nanoparticles have the potential to cause some undesirable side effects, including phytotoxicity and suppression of germination (Rajput et al., 2020a). However, according to Abbasi Khalaki et al. (2020), certain nanoparticles have the ability to stimulate cellular signalling pathways. This, in turn, improves seed metabolism, seedling vigour, and overall plant development. The characteristics of nanoparticles, including their size, concentration, and zeta potential, are what ultimately determine how biological reactions occur (Abbasi Khalaki et al., 2020; Acharya et al., 2019; Singh et al., 2021). These characteristics are crucial for the uptake and movement of nanoparticles in plants. For example, smaller nanoparticles are better at getting through biological barriers (Rajput et al., 2022). In addition to this, the charge over the surface of the nanoparticles is extremely important. Nanoparticles with both positive and negative charges can be absorbed by the foliage and transmitted to the roots.However, the roots quickly absorb only nanoparticles with a negative charge. The presence of positive charges prevents plants from absorbing specific substances, leading to their formation of mucilage (Avellan et al., 2017; Spielman-Sun et al., 2019). Seeds can be nanoprimed to keep them safe during storage, speed up germination and help keep it synchronised, increase crop tolerance to biotic and abiotic stress, and facilitate plant development—all while reducing the need for fertilisers and pesticides (Malik et al., 2020; Marina Voloshina, 2020. Recent research has shown that seed nanopriming has the ability to activate various genes during germination, some of which are involved in the tolerance of plant stress.

There has been promising research in the area of using nanotechnology for seed priming (Hussain et al., 2019; Ye et al., 2020), but this is still relatively new. Utilisation of nano-priming in seed for seed protection has been suggested by Hussain et al. (2019) and Pirzada et al. (2020), due to the fact that there

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