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# NANO-ENABLED SEEDS: A SUSTAINABLE LEAP IN AGRICULTURE

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**Abstract**:

A novel method called "Nano-priming" uses nanotechnology in conjunction with seed priming to enhance crop performance and early growth. Nanoparticles, which are incredibly tiny particles which readily penetrate the seed coat and cause beneficial changes within the seed, are applied to seeds during this process. Faster germination and stronger seedlings result from these nanoparticles assistance in accelerating water absorption, activating enzymes and enhancing the seed's internal energy systems. Additionally nano-priming increases the seed's resistance to stress brought on by high temperatures, poor soil or drought. This approach could improve agricultural yields in a sustainable manner and lessen the demand for chemical fertilizers. Given the growing difficulties facing agriculture as a result of soil erosion and climate change, nano-priming presents a viable environmentally responsible way to boost global food security.

**Key words**: germination, nano-priming, seed science

**Introduction:**

The quality seeds, which form the basis of agriculture has a direct impact on agricultural yield and food security. To increase germination rates and early seedling growth traditional seed priming techniques including soaking seeds in water or nutrient solutions have been employed for a long time (Poole *et al*.,2003). However, a more potent method called nano-priming has been developed as a result of recent developments in nanotechnology. With this novel method, seeds are treated with nanoparticles which are ultrafine materials that can interact with seeds at the cellular and molecular level. Nanoparticles are usually smaller than 100 nanometers. By encouraging quicker water uptake, enhancing enzyme activity and fortifying antioxidant defenses, nano-priming in contrast to conventional priming improves the physiological and biochemical responses of seeds (Bhushan 2017). In addition to accelerating germination these effects increase seedling vigor and resilience to environmental stressors such heat, salinity, and drought. As worries about soil erosion, climate change, and excessive pesticide use mount, nano-priming presents a viable and effective way to boost crop productivity and agricultural resilience (Ramsden 2016).

**Nano priming of seeds:**

The process of exposing seeds to nanoparticles to improve germination, seedling growth, and stress tolerance is known as "seed nano-priming." It uses the special qualities of nanoparticles to interact with seed tissues, improving water uptake, activating metabolic pathways and inducing stress response mechanisms. Nanoparticles can improve the rate of water uptake by seeds, which facilitates faster and more uniform germination (Abbasi *et al.,*2021). Nanoparticles such as carbon nanotubes (CNTs), carbon dots and graphene oxide have been demonstrated to stimulate cellular processes in seeds including nutrient uptake and metabolism which improves seedling growth. The movement of nutrients and growth regulators within the plant can also be improved by the physical interaction between nanoparticles and seed cell membranes (Rhaman *et al*.,2022). Seeds that have been nano-primed are more resilient to a range of environmental stressors, including salt, drought and high temperatures. It has been claimed that nanoparticles such as silver (Ag) and zinc oxide (ZnO) improve plants' resistance to abiotic stressors by stabilizing

cellular structures and triggering antioxidant processes that lessen oxidative damage. When employed in nano-priming, some nanoparticles—particularly copper and silver nanoparticles—display antimicrobial qualities that can aid in shielding seeds from bacterial, viral and fungal infections. Nano-priming promotes sustainable agricultural methods by lowering the demand for chemical pesticides and improving seedling health by reducing seed-borne illnesses (Thakur *et al*.,2022).

**Mechanism of Nano seed priming:**

Nanoparticles increase the permeability of the seed coat, allowing water to enter more quickly. This early hydration is critical for "waking up" the seed and initiating the germination process. Key enzymes like amylase and catalase are stimulated by nanoparticles, releasing energy needed for growth and breaking down food that has been stored in the seed (Dutta *et al*.,2021). Because of their fast cellular activity germinating seeds frequently suffer from oxidative stress. Antioxidant enzymes that shield the seed from cellular harm are activated by nano-priming, guaranteeing healthier seedlings (Nile *et al*.,2022). Nanoparticles based on nutrients like nano-iron or nano-zinc give the seed vital micronutrients directly. In the early stages of growth, this encourages improved root and shoot development (Song *et al.,*2021). Extreme temperatures, salt and drought are just a few of the environmental challenges that nano-primed seedlings frequently exhibit better resilience to. Both enhanced internal defense systems and increased nutrient utilization efficiency are to blame for this.

**Table 1: Nano-particles and their effect of seed parameters**

| **Nano particles** | **Seed** | **Effect of NPs** | **Reference** |
|---|---|---|---|
| Au | South Indian Olibanum | Seed germination, seedling growth | Savithramma *et al*. (2012) |
| Ag | *Thymus kotschyanus* | Increase in Germination percentage, root and shoot length, wet and dry weight, vigor index | Abbasi *et al*. (2016) |
| Au | Maize | Improved their germination without any toxicity | Arnott *et al*. (2021) |
| CuO | Parsley | Increase in shoot and root length, fresh weight, and chlorophyll content | Dehkourdi and Mosavi (2013) |
| Cobalt and molybdenum oxide NPs | Soybean | Improved seed vigor and plant morphology with increased biomass | Chau *et al*. (2019) |
| Silver NPs | Watermelon | Improved seed vigor and plant morphology | Acharya *et al*. (2020) |
| nZVI<br>Nano zero - valent iron | Groundnut | Promote the germination rate | Zhang *et al*. (2015) |
| Fe NPs | Cowpea | The increased seed weight, leaf chlorophyll and Fe content | Delfani *et al.* (2014) |
| Iron (II) sulfide aqua NPs | Rice | Improved seed vigor and disease resistance | Ahuja *et al*. (2019) |

**Conclusion:**

By providing creative answers to pressing global issues like food security, crop productivity and sustainability, nanotechnology has the potential to completely transform seed science and advance agricultural practices. There are intriguing prospects to improve seed quality, nutrient uptake and resistance to environmental challenges and diseases through the use of nanomaterials in seed treatment, bio-fortification, germination improvement and stress tolerance. Nanotechnology can increase crop yields, lessen the environmental impact of farming and improve the nutritional content of crops by using nanoparticles for targeted distribution, controlled release and effective nutrient absorption. However, a number of obstacles must be overcome before nanotechnology in seed science may be widely used, including cost-effectiveness, environmental impact, safety concerns and regulatory barriers. To comprehend the long-term impacts of nanoparticles on plant systems, ecosystems and human health, more research is necessary. Nanotechnology could play a significant role in sustainable agriculture as research and technology develop, resulting in more resilient farming methods, healthier crops and increased food security. However to guarantee that nanotechnology is applied safely and responsibly for the benefit of both agriculture and society, a balanced approach to innovation and regulation is necessary.

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