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**POPULAR ARTICLE**

**Nanopriming and seed coating useful for sustainable agriculture**

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**Importance**

Nanopriming is a seed treatment method that uses nanoparticles to improve seed germination, seedling growth, and stress tolerance in plants. It involves soaking seeds in a solution containing nanoparticles of materials like metals or metal oxides, which enhances nutrient uptake, enzyme activity, and antioxidant defenses compared to traditional priming methods. This technique shows promise for boosting crop resilience and yield but requires more research to understand its full mechanisms and long-term environmental impact.

**How it works**

**Enhanced germination and growth:**

Nanoparticles can trigger a more rapid and vigorous germination process by enhancing the activity of enzymes involved in breaking down stored food reserves in the seed.

**Improved nutrient absorption:** The small size and large surface area of nanoparticles allow for better absorption of nutrients, which can then be utilized during the early stages of growth.

**Increased stress tolerance:** Nanopriming can help plants better withstand environmental stresses like drought or salinity. This is partly achieved by triggering the plant's own antioxidant defense systems to combat reactive oxygen species (ROS).

**Modulation of plant hormones:** It can influence the levels of plant hormones (phytohormones), which are crucial for regulating growth and development.

**Key aspects**

**Nanomaterials:** A variety of nanoparticles are used, including metal-based nanoparticles (e.g., silver, zinc), metal oxides (e.g., titanium dioxide), and silica-based nanoparticles.

**Effectiveness depends on many factors:** The success of nanopriming is highly dependent on the specific type of nanoparticle, its size, shape, concentration, and the plant's genetic makeup.

**Comparison to traditional methods:**

Nanopriming is often more effective than traditional methods like hydropriming (soaking seeds in plain water) or priming with bulk materials.

Thorough evaluation of potential long-term environmental effects is necessary before widespread adoption. Nanopriming is a seed treatment technique that uses nanoparticles to enhance seed germination, growth, and stress resistance. By soaking seeds in a solution containing nanoparticles, this method can trigger physiological changes like increased water uptake, improved antioxidant activity, and faster starch breakdown, leading to better plant performance and yield. It is considered a tool for sustainable agriculture that can also biofortify crops with essential micronutrients.

Nanopriming is a sustainable agriculture technique that treats seeds with nanoparticles (NPs) to improve plant growth, germination, and stress tolerance. This method enhances seed metabolism and signaling pathways, leading to vigorous plants with higher yields and nutritional quality while reducing the need for fertilizers and pesticides. It works by creating nano-pores for better water intake, activating antioxidant mechanisms, and allowing for targeted, controlled release of beneficial substances.

### **Benefits of nanopriming**

**Improved germination:** Stimulates the expression of aquaporins and increases amylase production, leading to faster and more synchronized germination.

**Enhanced plant growth and development:** Results in more vigorous seedlings and plants that grow faster, improving their ability to compete with weeds.

**Increased stress tolerance:** Boosts a plant's ability to withstand both abiotic (e.g., salinity, drought, heavy metals) and biotic (e.g., fungal diseases) stresses.

**Improved nutrient uptake and quality:** Allows for targeted delivery of nutrients, potentially leading to higher food quality and reduced fertilizer use.

**Seed protection:** Some NPs have antimicrobial properties, helping to protect seeds from pathogens during storage and early growth.

How it works

**Targeted delivery:** Nanopriming delivers nutrients or other beneficial substances directly to the seed, which is more efficient than foliar spray or soil application.

**Controlled release:** It allows for the sustained release of beneficial substances during critical early growth stages.

**Cellular effects:** NPs can create nano-pores in the shoot, improve water intake, and activate antioxidant and reactive oxygen species (ROS) mechanisms within the seed.

**Metabolic and signaling modulation:** By interacting with the seed's internal systems, NPs can alter metabolism and signaling pathways, which helps prepare the seed for better performance.

### **Considerations**

**Plant-specific outcomes:** The exact physiological outcome is dependent on the specific plant genotype, as well as the composition, size, shape, and concentration of the nanoparticles used.

**Further research needed:** While promising, more research is needed to fully understand the molecular mechanisms, investigate the long-term environmental impacts, and assess efficacy under different stress conditions.

### **Mechanisms of nanopriming**

**Enhanced water absorption:** Nanoparticles create nanopores on the seed surface, facilitating quicker water uptake and increasing the expression of aquaporin genes, which are involved in water transport.

**Reactive oxygen species (ROS) regulation:** Nanopriming activates antioxidant enzymes to manage ROS, which acts as a signaling molecule to trigger downstream plant defense and growth mechanisms, such as boosting the expression of genes for antioxidant enzymes like SOD, POD, and CAT.

**Starch and sugar metabolism:** It stimulates the production of  $\alpha$ -amylase, which breaks down stored starch into soluble sugars, providing energy for the embryo during germination.

**Cell wall modification:** Nanoparticles can promote the formation of hydroxyl radicals, which can help loosen the cell walls, facilitating cell expansion.

**Nutrient uptake and biofortification:**

Nanopriming can improve a plant's ability to absorb and accumulate micronutrients, such as zinc, iron, and selenium, leading to biofortified crops with higher nutritional content.

**Applications and benefits**

Improved germination: Nanoprimed seeds show improved germination percentages and faster germination rates.

**Enhanced stress tolerance:** It helps plants better withstand abiotic stresses like drought, salinity, and extreme temperatures by improving water use efficiency and oxidative stress management.

**Biostimulation:** It can stimulate overall plant growth and development, potentially increasing crop yield.

**Sustainable agriculture:** Nanopriming is an emerging technology that can contribute to sustainable food production by increasing crop productivity and quality.

**Future directions**

More research is needed to fully understand the molecular mechanisms behind nanopriming's effects.

Extensive field trials are required to validate laboratory findings under real-world agricultural conditions.

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