

EXPLORING THE REVOLUTIONARY IMPACTS OF NANOPARTICLES IN SEED PRODUCTION

Madhwendra Kumar Pathak

Sam Higginbottom University of Agriculture, technology and Sciences,

Naini Prayagraj- 211007 U.P. (India)

Corresponding mail- kumarmadhwendrapathak97@gmail.com

INTRODUCTION

Nanotechnology, mostly in application of the Nanoparticles, has started revolutionizing seed science and technology providing to some extent answers to most critical concerns in agriculture. The distinctive features of nanoparticles, such the huge surface area to volume ratio and the peculiar chemical properties, enable them to interact with seeds that can provide germination, growth and yield (Nair *et. al.*, 2010). It is possible to understand the meticulous interplay of nanoparticles and seeds at the level of molecule. Nanoparticles can penetrate the testa (seed coat) and get inside the embryo which in turn modifies the metabolic processes, bringing in quicker germination and growth. They can also act as a shield against diseases and pests which will, in turn, increase the yield and immunity of plant (Khot *et al.*, 2012). To the agricultural scenario in India that is at the focal point of the country economy, the application of nanoparticles in the seed science would bring about a remarkable

transformation. Agriculture in India, being primarily an agriculture-based country, possesses a range of challenges including low productivity, pest infestation, and adverse climatic conditions. With its seed germination and growth enhancement capability, nanoparticles are alleviating the mentioned challenges. Nevertheless, the utilization of nanoparticles in the field of seed science is not an Easy task. Moreover, risks regarding the possible ecological and health hazards of nanoparticles must be considered. Hence, robust investigative study and analysis of risks prior to their full-scale usage in agriculture is paramount. This article will dive into the nanoparticles in seed science, the effect on the seed technology and prospects of this new domain. It will as well cover the successful achievements of nanoparticles in Indian agriculture as well as challenges and

opportunities of nanoformulated seed science and technology.

IMPACT OF NANOPARTICLES ON SEED PRODUCTION

Seed production technology has been found to be a revolutionary material in the use of nanoparticles. Nanoparticles can

affect and modify various physical and chemical processes that naturally help in improving the quality of higher production

amounts, scalability – both seed volumes strength. With the help of nanotechnology, it is very effective in increasing the overall yield quantity which can provide a safe and cost-effective path to make larger seed stocks. The best way how to integrate nanotechnology into seed production is the introduction of a new, protective layer as part of present systems. The layer that is produced by nanoparticles support a broader range of minerals, vitamins and hormones which contribute to seed growth as well as health. Production of new layers using nanoparticles has also been found to help cut down pest and disease levels that may limit the scalability of seed production. Nanoparticle concentrations can also benefit seed production with increased adhesion to nutrients including nitrogen and phosphorus. It has been discovered that nanoparticles exhibit outstanding performance in forming reliable bonds on the surface of seeds, resulting to a faithful adhesion and transport of essential nutrients. This has been proved to be successful approach for enhancing the nutritional value of seeds; this also gives encouragement by higher yields and scal nano formulations have made huge impact on revolutionizing seed industry. Materials for nanoparticles include metals and metal

oxides, ceramics and polymers with sizes between 1-100nm. These particles prove a great potential to enhance the seed germination and growth of various crop families capitalizing on their size. Seed production has seen the application of nanoparticles in many ways. For instance, the coating of seeds with ferrite nanoparticles can create an electromagnetic field on their surface which delivers oxygen and other elements necessary for complete germination. Silica nanoparticles, on the other hand, serve as a fertilizing agent when applied to seed surfaces. Zinc oxide nanoparticles therefore act as a protective coat that provides protection from temperature, UV rays and other environmental factors. Moreover, copper nanoparticles have been employed for controlling fungal and bacterial growth on the seeds. All these applications of nanoparticles in seed production have a significant effect. Nanoparticles help in preserving the seeds from external factors thereby enhancing their shelf life and germination rates. Studies have also shown that growth of plants in the initial stages is more after applying nanoparticles during seed production. This enables the farmers to harvest more crops that result into high economic performance. Seed production

has been made possible by nanoparticles. Nanoparticles play a vital role in protecting the seed by prolonging its shelf life and increasing germination

rates so that farmers can acquire high yield with effective growth cycles. This means that growers can be more successful and earn a stable income.

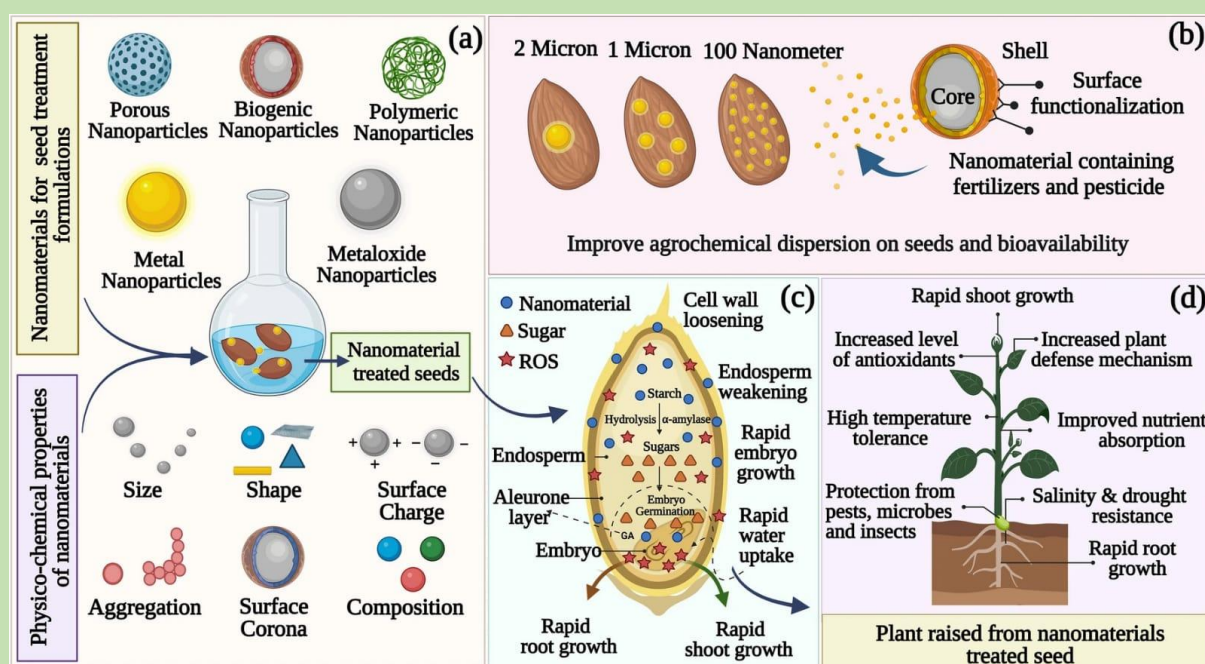


Fig.1. Application of nanomaterials in seed germination and plant development (a) Nanoparticles' properties (such as size, shape, surface charges, composition, and concentration) affecting the seed interaction. (b) Surface-engineered nanoparticles with the desirable properties for seed treatments. (c) Nanoparticles induced seed metabolism. d Nanoparticles effect for the improvement growth and establishment of plants. Shelar *et. al.*,(2023)

Table: Applications of Nanoparticles in Seed Production

Nanoparticle Type	Application
Ferrite nanoparticles	Create an electromagnetic field on seed surface to deliver oxygen and other elements necessary for complete germination
Silica nanoparticles	Serve as a fertilizing agent when applied to seed surfaces
Zinc oxide nanoparticles	Act as a protective coat that provides protection from temperature, UV rays, and other environmental factors
Copper nanoparticles	Employed for controlling fungal and bacterial growth on the seeds
Metal nanoparticles	Increase seed germination and biomass yield, and improve seed resistance to biotic and abiotic stresses
Nanoparticles derived from metals or their compounds	Used as carriers for nutrients and other substances of interest
Nanoparticle-mediated seed priming	Improves seed germination, seed growth, and yield by providing resistance
Seed priming using nanoparticles	Develops electron exchange, induces the formation of nanopores in shoot, and helps in the uptake of water absorption activates reactive oxygen species (ROS)/antioxidant mechanisms in seeds, and forms hydroxyl radicals to loosen the walls of the cells and acts as an inducer for rapid growth

POTENTIAL FUTURE OF NANOTECHNOLOGY IN SEED SCIENCE

Due to the fact that nanotechnology is one of quickly developing spheres with great contribution in seed science, When scientists use nanoparticles, they can shorten the plant development period and increase crop production while also making agriculture more environmentally friendly. Nanoparticles can be added to seed coating and deliver nutrients as well as pesticides directly at the seeds level which makes germination faster develops more rapidly. Nutritional, germination, and pest and disease resistance of seed quality can also be improved using the technology. Nanotechnology can also help increase yields. For instance, nano-infused seed coatings can lead to the mitigation of fluctuations in temperature which could control seeds' temperatures more efficiently and results in increased yields. Further, nanoparticles associated with stem or root system improve water and nutrient transfer efficiency thus increasing production levels without further fertilizer application to this crop

nor increased irrigation inputs. Nanotechnology in seed science goes beyond agriculture. As well as this, it has also been applied to the creation of novel food sources; where scientists are able to generate tougher and more nutritional plants in a shorter amount of time.

Apart from this, nanoparticles can be used to produce seed coatings that make transfer of genetic modifications easier for the creation of more durable plants resistant against pathogens. In general, nanotechnology is capable of changing the principles associated with seed science. It can shorten the time required for seed development, increase crop yields and make agriculture a more environmentally friendly process. Nano-infused seed coatings also ameliorates nutritional composition and disease resistance. Last, nanotechnology is able to produce plants with new more hardy characteristics for use as food sources.

SUMMARY AND CONCLUSION

In this paper, there is outlined the revolutionary effects of nanoparticles on seed science and

technology. Nanoparticles are the particles that have a size of 1–100 nm with atoms or molecules, which is nothing but

microscopic particles. This is because these particles have interesting characters that can help produce altered seeds designed for enhanced performance. Several major uses of nanoparticles in agriculture could be enhancing the lifespan of seeds, improving productivity levels and disease management, strengthening soil fertility as well as providing enhanced nourishment. Moreover, nanoparticles can be incorporated into various delivery systems including biopolymers coatings and nano therapeutics that make seed performance almost perfect. In agricultural and horticultural practices, nanotechnology products in the form of

nano-coated seeds as well as other nanoparticles are being increasingly used to improve yield. It has been concluded that nanoparticles provide several opportunities in seed science and technology. It is possible to use them as seed modifying and performance-improving agents, which can be carried by multiple delivery systems. However, Nanotechnology has become more popular in the agricultural sector already and its future significance will grow further. Thus, with the increase of studies and breakthroughs that are being made day by day further aspects will be touched upon about nanoparticles for agriculture and seed science and technology.

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