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Nanoparticles and their Role in Agriculture

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ABSTRACT

Nanoparticles are emerging as a new age material for revolutionizing present agriculture. With the world's population expanding and farming area becoming less available, nanoparticle-mediated improved agriculture undoubtedly looks like a great option to improve the future. Nanoparticles are small sized large surface area particles which possess distinctive physicochemical properties. Farmers prefer nanoparticles because of their small size, ease of handling and transportation, extended shelf life, and superior effectiveness. In the present scenario, agriculture has been facing a lot of challenges such as erratic climate change, soil contamination with a variety of harmful environmental pollutants like pesticides, fertilizers etc. Nanoparticles provides a solution to that and opens up new possibilities for improving the current farming practices through enhanced plant germination, higher disease resistance, better nutrient utilization and increased crop production. Nanoparticles can actually provide several benefits in comparison to the conventional agricultural practices and helps in slow, controlled and targeted delivery of

its constituents resulting in improved crop productivity. Hence, nanoparticles deliver a better solution to improve agriculture and food security.

INTRODUCTION

Nanoparticles are microscopic particles of matter at nanoscale level i.e. in the range of 1-100 nanometres (nm) in diameter (Figure 1). They are tiny particles which are too small to be seen by the naked eye. The prefix "nano" arise from the Greek word nanos, which means "dwarf," and it symbolizes one-billionth (10-9) of a unit. In scientific contexts, the word "nano" is generally used to denote those things which are on the nanometre scale, like nanotechnology, nanoparticles, and nanoscale materials, which are specifically in the range of 1-100 nm (Rajput et al., 2018). Such a nanometre scale is crucial because the properties of the materials at this scale can change dramatically. Hence, nanoparticles often show unique and exclusive physical, chemical, mechanical, and optical properties which are very different in comparison to those of the larger bulk materials of the same composition (Parveen et al., 2022). Nanoparticles can be classified on the basis of numerous factors like their shape, size, structure, and composition. Each factor can significantly influence their properties as well as potential applications. Therefore, they can be of various shapes and sizes, have good electron capturing capacity, optic absorption, conductivity, and photoluminescence as compared to their larger material counterparts. Since they have small size and large surface area, so they possess unique physical as well as chemical properties.

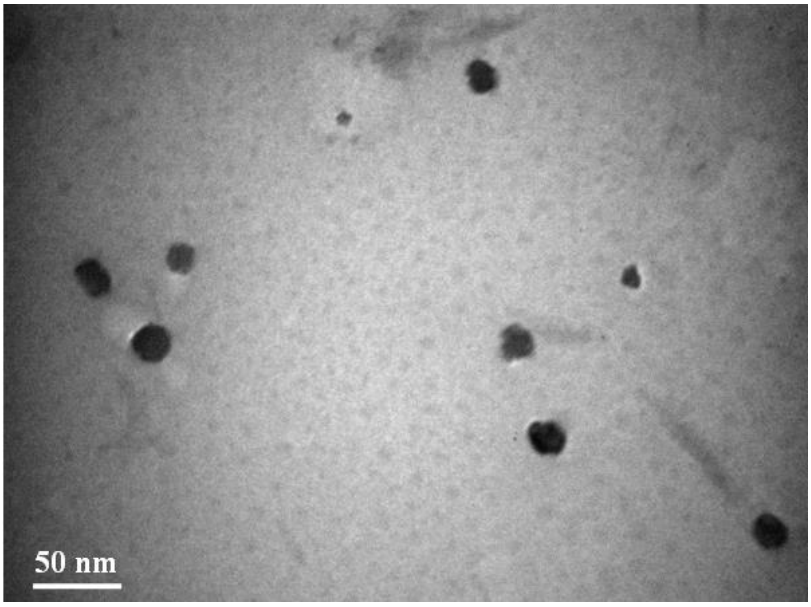

Figure 1. Transmission Electron Microscopic (TEM) Image of Nanoparticles

APPROACHES OF NANOPARTICLE SYNTHESIS

Nanoparticles can be synthesized through several methods, but nowadays researchers are focusing on green methods of synthesis of nanoparticles which is considered as the safest and eco-friendly method for its synthesis (Mirza et al., 2021). Generally, for the synthesis of nanoparticles, two main approaches are being followed i.e. Top-down approach and Bottom-up approach (Abid et al., 2022; Figure 2):

(i) **Top-down approach:** This is kind of destructive approach in which larger molecules breakdown into smaller units. The top-down approaches are generally more time and power consuming, but form environmental point of view they are important as they are environment-friendly because they release little or no gases during the synthesis of nanoparticles.

(ii) **Bottom-up approach:** This is a kind of building up approach in which simpler substances unites to form nanoparticles. Bottom-up approaches gives more uniform nanoparticles in terms of shape, size, as well as chemical composition due to which this approach is considered favourable for nanoparticles production.

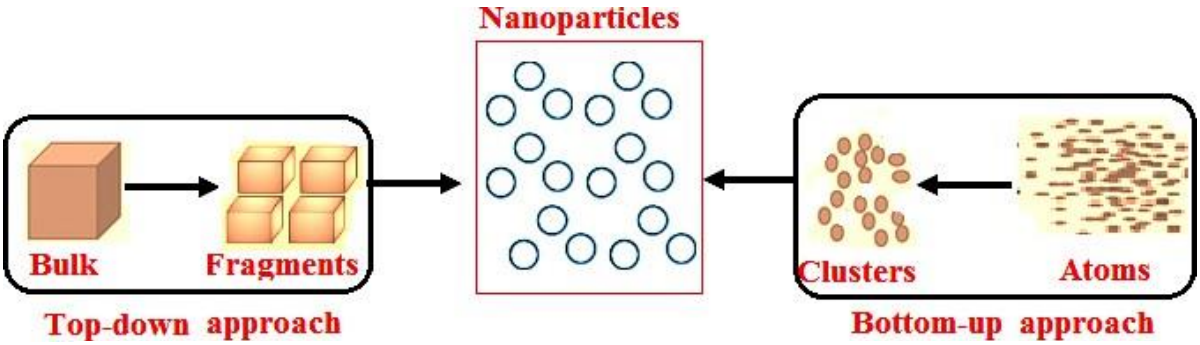

Figure 2. Top-down and Bottom-up approaches for the synthesis of nanoparticles

Nanoparticles have higher surface area which makes it highly useful in several ways. Due to the high surface area to volume ratio, the nanoparticles have a widespread range of potential applications. Therefore, the use of nanoparticles in agriculture has been explored as an excellent alternative to the conventional use of bulk chemical pesticides and fertilizers (Kalwani et al., 2022).

ROLE OF NANOPARTICLES IN AGRICULTURE

Nanoparticles are new age materials which can revolutionize agriculture (Shahid et al., 2024). With the aid of these novel materials, modern agriculture is evolving into precision agriculture that aims to maximize output from the limited resources. If applied properly, nanoparticles may offer a number of advantages over the traditional/conventional farming methods, including high surface area to volume ratios, mass transfer capabilities, as well as the gradual, regulated, and targeted delivery of reduced nutrient/pesticide concentrations to increase crop productivity.

In agriculture, nanoparticles can also be employed as nanopesticides. Plant diseases and pests have become a threat to agriculture causing huge economic losses to the important crops (Shahid, 2023; Shahid et al., 2019, 2023). Farmers are extensively using the conventional pesticides to protect the plants (Shahid et al., 2016 a), but there is a need to go for alternative methods of protection (Shahid et al., 2016 b). In the present era, several nanoformulations of the pesticides are being developed which not only gives protection to plants but also are much better in comparison to health hazards caused by the conventional chemical pesticides. Although it is tricky and expensive to synthesize safe and effective pesticides, but nanotechnology is able to provide novel as well as improved solution to this. Not only for protection against several pests and diseases, but the nanoparticles can also be utilized as a

biomarker or quick diagnostic tool against a variety of pests and plant pathogens. They can be employed as an indicator to identify certain diseases or as a direct or indirect pathogen detection method (El-Khawaga et al., 2024). Precision and smart agriculture has benefited from nanosensors.

Similarly, the nano-forms of the fertilizers helps in increased uptake of nutrients by the plants which promotes the growth of plants. Nanoparticles also help in seed germination. The nanoparticles have the ability to penetrate the tough seed coatings and allow the importation of water which can increase growth and vigour. Crop-associated ecosystems including crops, soil health etc. are impacted by the unique physicochemical characteristics of nanoparticles, including their size, shape, surface chemistry, as well as the core metal that was used to synthesize them. The use of nanoparticles in agriculture seeks to decrease the quantity of products for plant protection and decrease nutrient losses to boost agricultural yields (Prasad et al., 2017).

CONCLUSION

Nanotechnology in agriculture sector is a novel and fast-emerging area of research explored to enhance the crop productivity by utilizing nano-sized agrochemicals at lower doses than conventional agrochemicals. Use of nanoparticles constitute a novel and smart technology with immense potential to modernize sustainable agriculture. Through improvement in plant germination, development, as well as resistance to biotic and abiotic stressors, their use can result in healthier crops with greater yields. Hence, choosing nanoparticles with the appropriate physicochemical characteristics and using them in agriculture in the right way is a wise choice for achieving sustainable agriculture and better plant performance. By lowering the amount of dangerous chemicals present, their use also increases the safety of food for humans and opens the door to a more sustainable and ecologically friendly agricultural system as a whole.

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CONFLICT OF INTEREST

All the authors declare no conflict of interest.

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