AgroScience Today

Popular Article

e-ISSN: 2583-0147

Volume 6 Issue 12
Page: 1189 - 1193

Nanotechnology - an approach for crop protection

Shumaila Shahid[1*], Mohd Shoeb Khan[2], Abdul Kareem[3] and Parshant Kaushik[4]

[1]Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi-110012, India.

[2]Department of Applied Sciences and Humanities, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi-110025, India.

[3]P.M.S. Degree College, Mau, India.

[4]Division of Agricultural Chemicals, Indian Agricultural Research Institute, New Delhi-110012, India.

*Corresponding author's e-mail: *shumaila24amu@gmail.com; shumaila@iari.res.in*

Published on: December 31, 2025

ABSTRACT

Nanotechnology holds significant promise in addressing numerous challenges faced by today's modern agriculture, including crop protection, nutrient management, as well as environmental sustainability. This the novel technology that revolutionizes crop protection by enabling target-based delivery of pesticides, early pest/pathogen detection, and controlled release of nutrients through nanomaterials, nanobiosensors, nanocapsules etc. Nanoparticles have dimensions ranging from 1-100 nanometers (nm) that act differently in comparison to their bulk-sized counterparts as they are smaller in size, have a larger surface area, greater charge, increased solubility and more stability. This leads to decreased usage and better efficacy of chemicals, minimized environmental contamination, as well as improved plant resilience against several stresses eventually increasing food security. Through minimizing the chemical load, it also reduces pollution and improves water usage. It also offers advanced monitoring which leads to smart farming. Hence, nanotechnology is the key for success to a long- term future in crop protection which can transform the agricultural sector more effectively and sustainably.

INTRODUCTION

The application of nanotechnology in the agriculture sector has the potential to revolutionize crop production and contribute to food security at the global level, especially in the face of rising challenges like diseases, pests, climate change, nutrient resource inefficiencies, etc. (Shahid, 2023). The increasing world population, which is estimated to reach up to around 9.7 billion by 2050, pose a significant challenge to the food production systems globally (Shahid et al., 2025a). As the demand for food increases, there is a corresponding pressing need and urgency for agricultural innovations and advancements in order to ensure sufficient, nutritious, and sustainable production of food (Shahid et al., 2023; Kaushik et al., 2024; Ansari et al., 2025a). Nanotechnology is increasingly recognized as a transformative tool in boosting the crop production as well as sustainability in agriculture. With the manipulation of materials at the nanoscale level (1-100 nm), nanotechnology can not only improve the proficiency of agricultural processes, but also enhance the crop yields, minimize the environmental impact, and support sustainable farming practices. The properties of the materials at this scale can change dramatically which shows the importance of a nanometre scale. With regard to crop protection, nanotechnology has become an important tool for sustainable agricultural development. The shortcomings associated with the synthetic fungicides can be overcome through the use of nanotechnology as it helps to increase the efficiency of inputs and at the same time minimizing relevant losses.

ROLE OF NANOTECHNOLOGY FOR CROP PROTECTION

Nanotechnology is being actively applied for crop protection through one of the several ways (Figure 1). It has immense importance for the strategies of crop protection and it has now become an important tool for the crop improvement (Shahid et al., 2025b).

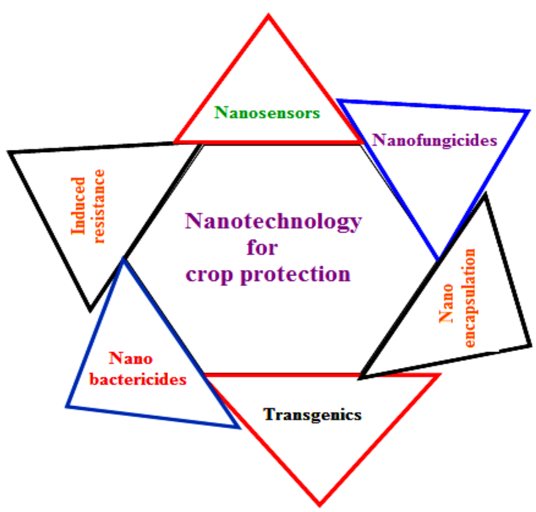

Figure 1. Nanotechnology for crop protection

Nanotechnology aids in encapsulating nanopesticides and developing active nanomaterials, including metallic and non-metallic nanoparticles. Even the composites of nanomaterials (nanocomposites) can also be used as active nanopesticide materials. These nanoparticles offer unique chemical, physical, biological, and optical properties as well as improved activity owing to their increased surface area. More than 90% of pesticides are lost or not able to reach their target sites required for the control of pests and/ pathogens (Nuruzzaman et al., 2016; Shahid et al., 2024a), increasing crop production costs and environmental degradation which necessitates the urgency for some alternative approaches to manage the plant diseases and/ pests (Shahid and Khan, 2016; 2019). In order to overcome this, nanoformulation of pesticides can be done in which tiny metallic nanoparticles are used that act as active ingredients (a.i.) of pesticides for crop protection practices. Metal and metal oxide nanoparticles such as silver, gold, zinc oxide, copper oxide, titanium oxide, magnesium oxide, etc. are utilized for synthesizing nanofungicides (Shahid et al., 2024b). These metal-based nanoparticles can be manufactured through several techniques including chemical, physical, and biological methods, which can be used for plant disease control through killing of pathogenic microorganisms like fungi, bacteria, virus etc. and also stimulating the immune system of plants (El-Khawaga et al., 2024; Shahid et al., 2024c).

Nanomaterials can enhance utilization of agrochemicals by acting as unique carriers of agrochemicals assisting in site-targeted controlled nutrient delivery in order to improve agrochemical utilization for sustainable crop protection. Nano-encapsulation of the pesticides in controlled release conditions is promising for future research to improve the efficacy of pesticides, reducing their volatilization and minimizing their toxicity ultimately preventing environmental contamination and helping in ecological sustainability. Polymer-based nano systems can be used for encapsulating materials and carbon nanotubes which act as carriers and active ingredients (a.i.) in nanopesticides. These engineered nano-encapsulated agrochemicals help to release the a.i. in a controlled and targeted way.

Nanosensors use in precision farming have considerably improved human control of plant and soil health, their quality, as well as safety assurance (Ansari et al., 2025b). Nowadays, nanosensors are being developed for monitoring of crop growth, diseases, nutrient deficiency, soil conditions, and environmental entry of agrochemicals, which helps in contributing to sustainable agriculture as well as environmental systems (Mukhtar et al., 2025). They support high-tech agricultural farms as they have direct and projected uses in the precise management and regulation of chemicals and nanobiosensors. During the growing season of cultivated crops, the nanosensor-based global positioning system (GPS) is very well used for the real time monitoring of fields. Therefore, the combination of nanotechnology and biology for the development of nanosensors has significantly improved their potential to sense as well as detect any kind of impairments in the environmental conditions (Shang et al., 2019).

In transgenics also, nanoparticles offer good potential through pathogen resistance. They can impart the disease resistance in the crops which help in revolutionizing the agriculture (Hamid and Saleem, 2022). In this aspect also, the combination of nanotechnology and biotechnology can provide prospects for research in genetic engineering through modification of genes by molecular transporter, in order to produce new organisms. Silicon dioxide (SiO_2) nanoparticles have already been developed to deliver the DNA fragments to tobacco and corn plants without causing any adverse effects (Galbraith, 2007). Hence, nanosized systems offer higher potency, controlled release, bioavailability, targeted delivery, and degradation safety, which are the key features for agricultural applications to improve the agricultural crop production.

CONCLUSION

Nanotechnology is the novel technology which can enhance resource efficiency, and provide sustainable crop protection agriculture by addressing issues such as pathogen/pest control, drought resilience, nutrient management, and climate change, hence securing long-term food production on a global basis. It offers promising applications for precision and modern agriculture in addressing the unprecedented challenges like reduced crop yield because of nutrient deficiency, biotic/abiotic stresses as well as environmental degradation. Nanotechnology-based fungus management techniques help in reducing the environmental issues and solve the problem of increasing fungicide-resistant infections, permitting for environmentally useful site-specific pesticide usage. Hence, nanotechnology offers efficient crop protection methods and are progressing in agriculture to meet the increasing demand for food and environmental sustainability.

ACKNOWLEDGEMENTS

The authors are thankful to the Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, New Delhi.

CONFLICT OF INTEREST

All the authors declare no conflict of interest.

REFERENCES

Ansari, N. H., Shahid, S., Khan, M. S., Rizvi, N. Z., & Nagar, M. R. (2025). Applications of nanobiosensors in agriculture. In *Smart nanomaterials: A sensor approach*. Springer Nature. https://doi.org/10.1007/978-981-96-3878-9_12

Ansari, N. H., Shahid, S., Khan, M. S., Rizvi, N. Z., Iqubal, S. M. S., & Bahfi, A. (2025). Biosurfactants: Effective and ecofriendly materials for attaining sustainable agriculture and environmental safety. *Colloid Journal*, 78–100.

El-Khawaga, A. M., Mukhtar, S., & Shahid, S. (2024). Sustainable nanomaterials as promising antibacterial agents. In I. Uddin & I. Ahmad (Eds.), *Sustainable nanomaterials: Synthesis and environmental applications* (pp. 203–225). Springer Nature.

Galbraith, D. W. (2007). Nanobiotechnology—Silica breaks through in plants. *Nature Nanotechnology, 2*, 272–273.

Hamid, A., & Saleem, S. (2022). Role of nanoparticles in management of plant pathogens and scope in plant transgenics for imparting disease resistance. *Plant Protection Science, 58*(3), 173–184.

Kaushik, P., Yadav, D., Tripathi, K., Shakil, N., Rana, V., & Shahi, S. (2024). Synthesis and antifungal activity of novel imidazole derivatives. *ACS Agricultural Science & Technology, 5*(1), 108–114.

Mukhtar, S., Ali, A., Aryan, S., Shahid, S., Akhtar, M. N., Hidalgo, J. S., Umar, M., & El-Khawaga, A. M. (2025). Carbon-based smart sensors for environmental pollution detection. In *Smart nanomaterials: A sensor approach* (pp. 143–153). Springer Nature.

Nuruzzaman, M., Rahman, M. M., Liu, Y. J., & Naidu, R. (2016). Nanoencapsulation, nano-guard for pesticides: A new window for safe application. *Journal of Agricultural and Food Chemistry, 64*, 1447–1483.

Shahid, S. (2023). Plant diseases—A major limiting factor in production of pulses (mung bean and chickpea). In S. Shahid, P. Singh, & B. Neog (Eds.), *Recent research in agriculture and plant sciences* (pp. 1–18). MKSES Publication.

Shahid, S., & Khan, M. R. (2016). Biological control of root-rot on mungbean plants incited by *Macrophomina phaseolina* through microbial antagonists. *Plant Pathology Journal, 15*, 27–39.

Shahid, S., & Khan, M. R. (2019). Evaluation of biocontrol agents for the management of root-rot of mungbean caused by *Macrophomina phaseolina*. *Indian Phytopathology, 72*, 89–98.

Shahid, S., Ansari, N. H., Khan, F. A., Khan, M. S., & Rizvi, N. Z. (2025). Surfactants as adjuvants in agriculture. *Food and Scientific Reports, 6*(1), 51–54.

Shahid, S., Ansari, N. H., Khan, M. S., Khan, F. A., & Rizvi, N. Z. (2024). Nanoparticles and their role in agriculture. *Agroscience Today, 5*(12), 1019–1023.

Shahid, S., Khan, M. S., Khan, F. A., Rizvi, N. Z., & Kaushik, P. (2024). Silver nanoparticles in fungal plant pathogen management. *Agroscience Today, 5*(12), 1024–1029.

Shahid, S., Khan, M. S., Kumar, A., Rahman, S., Arshad, M., Kaushik, P., Saini, P., & El-Khawaga, A. M. (2024). Role of nanomaterials in sustainable agriculture. In I. Uddin & I. Ahmad (Eds.), *Sustainable nanomaterials: Synthesis and environmental applications* (pp. 227–248). Springer Nature.

Shahid, S., Kumar, A., Khan, M. S., Ansari, N. H., Kareem, A., Nagar, M. R., Rizvi, N. Z., Rahman, S., Ahmad, S., & Kaushik, P. (2025). Sustainable synthesis of cucumber-derived gold and silver nanoparticles: Impact on mungbean root-rot disease suppression and organic LED performance. *Frontiers in Nanotechnology, 7*, 1572639.

Shahid, S., Sharma, B. B., Khan, A. A., & Ansari, N. H. (2023). Management of plant diseases by surfactants. *International Journal of Tropical Agriculture, 41*, 121–127.

Shang, Y., Hasan, M. K., Ahammed, G. J., Li, M., Yin, H., & Zhou, J. (2019). Applications of nanotechnology in plant growth and crop protection: A review. *Molecules, 24*(14), 2558.