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The Potential and Diversified Role of Nanoparticles in Plant Science: A New Paradigm in Sustainable Agriculture

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Abstract

The rapid increase of population has increased the need of food in limited land. To mitigate the demand, a number of approaches are carried out which have disturbed the harmony with our beautiful nature resulting in severe environmental problems. Therefore, current sustainable approaches like nanotechnology can be the potential role player in reducing the harmful effect of other new technologies. The wide functional diversity of these nanoparticles in crop production and protection has shifted the conventional agriculture to "Nano agriculture". The huge amount of yield loss is mainly reported due to insect and pest responsible for a number of plant diseases. The rapid and more use of agrochemicals are more toxic and hazardous to all human beings and animals. Therefore, the nanotechnology can be the best alternative to agrochemicals with multiple benefits such as minimum use with maximum effect, low leaching, longer shelf life, eco-friendly and long-term effect. Furthermore, nanotechnology has major potential in present and future agriculture system through different approaches like monitoring and detecting pathogens, development of plant by pre-treatment agents, influencing plant growth hormones *etc*.

Key words: Nano particles, Nano technology, Plant protection, Sustainable agriculture.

The increased projection of population growth has questioned on the global food demand as it need to be doubled by 2050. But the sudden arrival of biotic and abiotic stress has disrupted the food production cycle which can be alarming in future days (Tilman *et al.,* 2011). The use of agrochemicals to get rid of biotic stresses are another challenging factor in sustainable agriculture system as they have toxic residual effect in environment as well as in food chain. A novel emerging and innovative method, nanotechnology was discovered about a half century ago for industrial application only, which afterwards attracted many researchers and crop scientist to implement this technique in an ecofriendly way to develop a green and sustainable agriculture strategy (Mukhopadhya and Sharma, 2013). With its wider and potential application in Agricultural sciences, it has become one of the promising approaches to target a broad range of pests (Ul Haq *et al.,* 2020). This technology includes a combination of methods and techniques to convert a material in to an ultramolecular level which is more reactive and potential. Application of chemicals is not suitable in sustainable agriculture due to its low-impact compounds and toxic residues in environment. The use of nanotechnology in agriculture aims to decrease the use of agrochemicals and to increase the nutrient uptake through nano-based fertilizers (El-Ghamry *et al.,* 2018). These nanoparticles show high permeability, stability and solubility. Role of nanoparticles on growth of some selected cereals were checked by Jyothi and Hebsur in 2017.

Nanoparticles (NP) are a minimum of 100 nm in size and made up of gold, silver, silicon, copper, titanium dioxide, zinc oxide and carbon. Due to large surface area to volume ratio and small size, they can absorb, react and carry compounds like DNA, RNA, proteins or small molecular drugs with high efficiency. They offer more advantages than agrochemicals by reducing toxic substances, increasing shelf life and improving solubility (Worrall *et al.*, 2018). These nanoparticles have the potential to work more effectively when directly applied to any plant parts such as roots, seeds, foliage *etc*. Two key mechanisms present behind the nanotechnology-based plant protection. Firstly, it can be directly applied as to protect crop and secondly, they act as carrier for the existing chemicals for effective delivery at target sites. The methods for synthesis of nanoparticles are quite diverse whereas the green nanoparticle synthesis is easy, rapid and conducted in ambient pressure and temperature. Without any doubt, more in depth research on agricultural nanotechnology surely leads towards new generation pesticides in upcoming days. In this review, we have discussed the potential effect and function of different nanoparticles on various plant pathogens.

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Potential effect of NPs against phytopathogens

In recent years, plants are mostly affected by many biotic agents which can cause a yield loss of up to 100%. Previous studies have shown that 20 to 40% yield loss was observed per year and 10% is only in fruit crops (Pattanayak and Das, 2020) .Nanoparticles are one of the new frontiers of sustainable agriculture. The direct effect of several nanoparticles has proved its potentiality against a wide range of plant pathogenic micro-organisms and insects through different approaches (Fig 1 and Table 1). The tremendous prospects of nanoparticles in monitoring and managing the pathogens can advance the existing and future agriculture by increasing the growth curve vertically.

Effect of silver NPs on phytopathogens

The potentiality of NPs has been examined in laboratory conditions as well as in open field conditions in different experiments. Several NPs have proved its effectiveness in suppressing a wide range of plant pathogens. Silver NPs are getting popular due to its “green synthesis” mechanism in plant pathogens (Das and Pattanayak 2020). In 2007, Kim and his coworkers tested the three different types of silver nanoparticles against plant pathogenic fungi like *Fusarium oxysporum f. sp. cucumerinum, Fusarium oxysporum f.sp. lycopersici, Fusarium solanum, Pythium aphanidernatum, Alternaria alternata, Alternaria brassicola, Cladosporium cucumerinum etc in vitro* and proved the inhibitory effect of silver NPs against the above pathogens. Many plant pathogenic bacteria and fungi such as *Magnaporthe grisea* and *Bipolaris sorokiniana* can also be suppressed significantly with the application of silver NPs (Jo *et al.*, 2009). Similarly, in another experiment, highest inhibitory effect was observed in case of *Proteus vulgaris, Escherichia coli* and *lowest in staphylococcus aureus*.

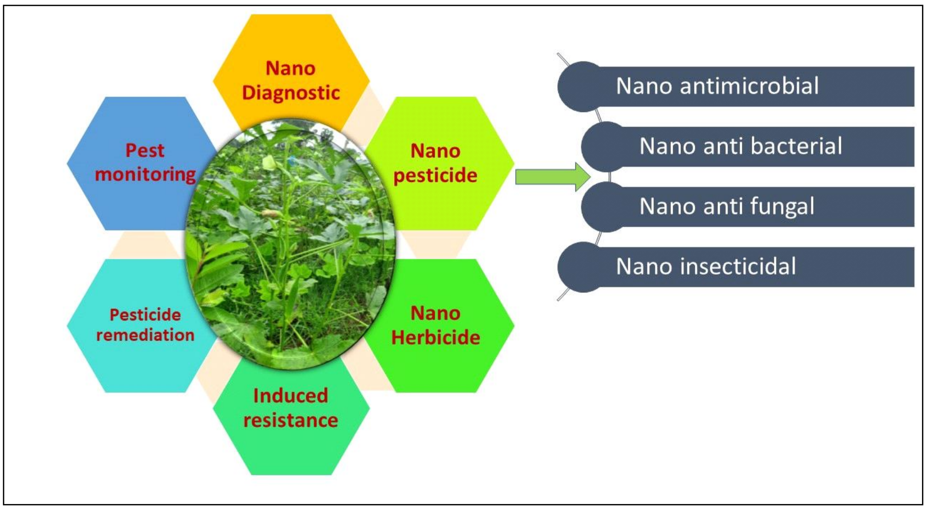

Fig 1: Application of nanotechnology in plant protection.

Table 1: Examples of different nano particles and their target insect pest.

Nanoparticles	Fungicides/ insecticide	Targeted pathogen/pest	Crops	References
Chitosan	Carbendazim	*A. Parasiticus* and *F. oxysporum*	Cucumber, maize and tomato	Kumar *et al.*, 2017
Silver	Propineb Fludioxonil Tebuconazole	*Bipolaris maydis*	Rice	Huang *et al.*, 2018
PVP	Tebuconazole	*Gloeophyllum trabeum*	Pine	Das and Pattanayak, 2020
Gold	Ferbam	-	Tea	Jia *et al.*, 2014
PVC	Chlorothalonil, Tebuconazole	*T. versicolor*	Pine	Das and Pattanayak, 2020
Silica	Clorfenapyr		*Brassica ehinese*	Jenne *et al.*, 2018
PHSN	Avermectin	*P. xylostella*	*Brassica oleracea*	Kaziem *et al.*, 2018
Sodium alginate	Imidaclopid	Leafhopper/Jassids		Kumar *et al.*, 2017
Zinc oxide	Azadirraehtin	-	*C. serratus*	Jenne *et al.*, 2018
Polydopamine	Avermectin		*Gossypium* and *Zea mays*	Jia *et al.*, 2014

Effect of zinc NPs on phytopathogens

Several zinc-based NPs are proved as one of the effective control measures against plant pathogenic fungi and bacteria. Antifungal activity has been observed in many zinc NPs against *Botrytis cinerea, Penicillium expansum* at 12 mmol L^{-1} (He *et al.,* 2018). Growth and morphological changes such as hyphae thinning, modification in clumping tendency *etc*, have been observed due to zinc NPs at 9mmol L^{-1} concentration (Arciniegas-Grijalba *et al.* 2017). Similarly, zinc NPs directly affect the colonization behavior of many bacteria *viz*. *Proteus aeruginosa in vitro* (Jayaseelan *et al.,* 2012). Characteristics of zinc NPs such as size and concentration are directly proportional to the effectiveness of NPs. It was observed that decrease in particle size of NPs resulted in increased antibacterial effect against *Escherichia coli* and *Staphylococcus aureus*.

Effect of Copper NPs on phytopathogens

Several copper formulated NPs are available commercially which are used to protect the plants against fungi. Copper based fungicides are playing a major role in plant disease management from early periods. These NPs mainly affect the DNA, protein and lipids resulting in suppression of the pathogenic fungi. An *in vitro* study has shown the inhibitory effect against several fungi like *Alternaria alternata, Phoma destructive, Curvularia lunata and Fusarium oxysporum* (Kanhed *et al.* 2013). A potential nanometallic fungicide was prepared by using high concentration of copper NPs in biological reduction method which proved its effectiveness against red root rot of tea. A mixture of Copper NPs with soda lime glass powder has tested against bacteria which proved its antibacterial effect against various gram positive and gram-negative bacteria. Pomegranate blight caused by *Xanthomonas axonopodis pv. punicae* can be controlled by the application of copper NPs (Mondal and Mani, 2012).

Influence of NPs as growth promoters in plants

Use of nanoparticles as a growth promoter is one of the new and novel techniques in agriculture. The NPs can play the role of biofertilizer to enhance the plant growth by supplying proper nutrients or making them available to the plant system. This ecofriendly approach has increased its popularity due to its sustainable characters such as high reactivity, higher bioactivity, surface effects *etc*. Nano biofertilizers are mostly used in farming to improve the nutrient efficiency. These are the modified form of synthetic fertilizers which help to improve the soil fertility, quality as well as enhance the quality of plant system by adding proteins, carbohydrates *etc*.

Nano fertilizers are mainly available in three types such as nanoscale fertilizer, nanoscale coating and nanoscale additives. These nano fertilizers can alter the seed vigor, increase chlorophyll formation to increase the photosynthesis rate which positively impacts the plant growth. Tarafdar *et al*., (2012) have observed the increase in availability and uptake of nutrients after foliar application of encapsulated nano fertilizers. Foliar application of zeolite-based nanoparticles can prevent the loss of nutrients through denitrification, leaching loss, volatilization or any other methods. Some nano fertilizers negatively impact the growth of plant by affecting the seedling growth and germination.

CONCLUSION

Intensive chemical based traditional agriculture system has resulted in increased yield but it has polluted our mother earth and affected human beings, animals and plants directly and indirectly. The implementation of Nano agriculture can shift this chemical agriculture system to a green sustainable agriculture system without any doubt. In recent years, nanoparticle has gained more interest due to its wider application in crop production such as pest monitoring and protection, plant growth promotion, potential role in plant hormone signaling pathway, defense response elicitors in plant, soil nutrients *etc* (Zhao *et al.,* 2018). Additionally, the application of nanoparticles is being explored in seed germination, delivery of plant hormone, transfer of target gene, nanosensors and nanobarcoding (Hayles *et al.,* 2017). Effect of nanoparticles on seed germination, growth and phytotoxicity and crop improvement was checked by Verma *et al*., (2021).

More effort is needed to bring this technology to farmers focus as very few farmers know about this. Government and non-government organizers should act in a cooperative manner to deliver this knowledge from lab to land. Most of the research areas have mainly focused on *in vitro* management of pathogens rather than in open field conditions. Still more research is required to check the efficacy in open field conditions. Researchers should emphasis on determining the translocation and intracellular biotransformation inside plant system which will help to gain in depth idea between the interaction of plant and nanoparticles.

Conflict of interest: None.

REFERENCES

Arciniegas-Grijalba, P.A., Patiño-Portela, M.C., Mosquera-Sánchez, L.P. *et al.* (2017). ZnO nanoparticles (ZnO-NPs) and their antifungal activity against coffee fungus Erythricium salmonicolor. Appl Nanosci. 7: 225-241.

Das, S. and Pattanayak, S. (2020). Nanotechnological Approaches in Sustainable Agriculture and Plant Disease Management. In: Organic Agriculture, Intech Open, Londan, UK, pp: 1-18.

El-Ghamry, A.M., Mosa, A.A., Alshaal, T.A., ElRamady, H.R. (2018). Nano fertilizers vs. biofertilizers: New insights. Environ Biodivers Soil Secur. 2: 51-72.

He, Y., Huang, G., An, C., Huang, J., Zhang, P., Chen, X., Xin, X. (2018). Reduction of Escherichia coli using ceramic disk filter decorated by nano-TiO2: A low-cost solution for household water purification. Sci. Total Environ. 616-617: 1628-1637.

Huang, W., Wang, C., Duan, H., Bi, Y., Wu, D., Du, J. *et al.* (2018). Synergistic antifungal effect of biosynthesized silver nanoparticles combined with fungicides. International Journal of Agriculture and Biology. 20: 1225-1229

Hayles, J., Johnson, L., Worthley, C., Losic, D. (2017). Nanopesticides. A review of current research and perspectives. New Pestic. Soil Sens. 193-225.

Jayaseelan, C. *et al* (2012). Efficacy of plant-mediated synthesized silver nanoparticles against hematophagous parasites. Parasitol Res. 111: 921-933.

Jenne, M., Kambham, M., Tollamadugu, N.P., Karanam, H.P., Tirupati, M.K., Balam, R.R., *et al.* (2018). The use of slow releasing nanoparticle encapsulated Azadirachtin formulations for the management of *Caryedon serratus* O. (groundnut bruchid). IET Nanobiotechnology. 12: 963-967.

Jia, X., Sheng, W.B., Li, W., Tong, Y.B., Liu, Z.Y., Zhou, F. (2014). Adhesive polydopamine coated avermectin microcapsules for prolonging foliar pesticide retention. ACS Applied Materials and Interfaces. 6: 19552-19558.

Jo, Y.K., Kim, B.H., Jung, G. (2009). Antifungal activity of silver ions and nanoparticles on phytopathogenic fungi. Plant Dis. 93(10): 1037-1043.

Jyothi, T.V. and Hebsur, N.S. (2017). Effect of nanofertilizers on growth and yield of selected cereals-A review. Agricultural Reviews. 38(2): 112-120.

Kaziem, A.E., Gao, Y., Zhang, Y., Qin, X., Xiao, Y., Zhang, Y. *et al.* (2018). Amylase triggered carriers based on cyclodextrin anchored hollow mesoporous silica for enhancing insecticidal activity of avermectin against *Plutella xylostella*. Journal of Hazardous Materials. 359: 213-221.

Kanhed, P., Birla, S., Gaikwad, S., Gade, A., Seabra, A.B., Rubilar, O., Duran, N., Rai, M. (2013). *In vitro* antifungal efficacy of copper nanoparticles against selected crop pathogenic fungi. Materials Letters. 115: 13-17

Kim, J.S., Kuk, E., Yu, K.N., Kim, J.H., Park, S.J., Lee, H. J. *et al* (2007). Antimicrobial effects of silver nanoparticles. Nanomed-Nanotechnol. 3(1): 95-101.

Kumar, S., Kumar, D., Dilbaghi, N. (2017). Preparation, characterization, and bio-efficacy evaluation of controlled release carbendazim-loaded polymeric nanoparticles. Environmental Science and Pollution Research. 24: 926-937.

Mondal, K.K., Mani, C. (2012). Investigation of the antibacterial properties of nanocopper against Xanthomonas axonopodis pv punicae, the incitant of pomegranate bacterial blight. Ann Microbiol. 62(2): 889-893.

Mukhopadhyay, S.S., Sharma, S. (2013). Nanoscience and nanotechnology. cracking prodigal farming. J. Bionano Sci. 7: 1-5.

Pattanayak, S. and Das, S (2020). A perspective on Integrated Disease Management Strategies in Minor Tropical Fruit Crops of India. In: Advanced Agriculture by S. Maitra and B. Pramanick (Editors) © New Delhi Publishers, New Delhi, pp: 142-163.

Subramanian, K.S., Manikandan, A., Thirunavukkarasu, M., Rahale, C.S. (2015). Nano-fertilizers for Balanced Crop Nutrition. In: Nanotechnologies in Food and Agriculture, [Rai, M. *et al* (eds)] 1st edn. Springer, Cham. 3: 69-80.

Tarafdar, J.C., Raliya, R., Rathore, I. (2012). Microbial synthesis of phosphorous nanoparticle from tri-calcium phosphate using Aspergillus tubingensis TFR-5. J. Bionanosci. 6(2): 84-89.

Tilman D, Balzer C, Hill J, Befort BL. (2011). Global food demand and the sustainable intensification of agriculture. PNAS 108(50): 20260-64.

Ul Haq I., Ijaz S., Khan N.A. (2020). Application of Nanotechnology for Integrated Plant Disease Management. In: Plant Disease Management Strategies for Sustainable Agriculture through Traditional and Modern Approaches. [Ul Haq I., Ijaz S. (eds)]. Sustainability in Plant and Crop Protection, Vol 13. Springer, Cham.

Verma, D.K. Patel, S. and Kushwah, K.S. (2021). Effect of nanoaparticles on seed germination, growth, phytotoxicity and crop improvement. Agricultural Reviews. 42(1): 1-11.

Worrall, E.A., Hamid, A., Mody, K.T., Mitter, N., Pappu, H.R. (2018). Nanotechnology for Plant Disease Management. Agronomy 8: 285.

Zhao, X., Meng, Z., Wang, Y., Chen, W., Sun, C., Cui, B., Cui, J., Yu, M., Zeng, Z., Guo, S., Luo, D., Cheng, J.Q., Zhang, R., Cui, H. (2018). Pollen magnetofection for genetic modification with magnetic nanoparticles as gene carriers. Nat Plants. 3: 956-964.