Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 05, Issue: 05 (SEP-OCT, 2025)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

How Helpful is Nanotechnology in Plant Protection?

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In the realm of technological and scientific advancement, nanotechnology is a pioneering and emergent discipline. With its wide range of applications, it is establishing itself as a crucial component of sciences, including strategies for targeting phytopathogens for disease diagnostics and management. Pesticides may benefit from nanotechnology by being less toxic, possessing a better shelf life and becoming more water-soluble, which can potentially have positive implications for the environment. This chapter reflected on the mechanisms and different nanoparticle-mediated crop protection strategies. Also, nanoparticles and nano-formulations are described together with their antimicrobial effect, potential and applications for managing plant diseases.

Keywords: Nanotechnology, Nanoparticles, Plant disease management, Copper nanoparticles, Silver nanoparticle.

Introduction

The frequency and severity of adverse weather conditions have elevated along with the worldwide average temperature in recent decades due to climate change. These alterations in the global climate are mostly a consequence of human activity and are accentuated by rising carbon dioxide concentration in the atmosphere. A rapidly changing climate affects the agricultural sector adversely as it relies entirely on climatic conditions, responsible for crop growth and yield while diseases and pests affecting productivity rank second in terms of influence. Additionally, there is a limited supply of natural resources, such as land, water for irrigation and soil nutrients, which are important components for crop cultivation. However, there is an immense increase in demand for food to meet the needs of the growing global population. In the present scenario, resource efficiency, farm mechanisation and modernization represent a way to secure those constraints to decrease crop production costs and increase outputs. However, chemicals have adverse effects on non-target species including the resurgence of the pathogen population, alteration in disease dynamics and development of resistance, despite having numerous advantages such as high availability, rapid action and reliability. Nanotechnology is an imminent tool used which may be to combat these emerging issues for managing diseases and plant health (Padmavathi and Anuradha, 2022).

Nanotechnology is the study and application of very small particles ranging between 1 nm and 100 nm. The remarkable characteristics of nanotechnology have increased interest in diverse research disciplines, especially engineering, chemistry, biology, physics and materials science. The size of the nanoparticle, which is an important aspect, affects its physical and chemical properties. In contrast to their corresponding macro state, nanomaterials exhibit completely unique and different physicochemical properties including optical qualities, chemical reactivity, mechanical strength and surface area which also make them suitable for a broad range of applications (Khan and Rizvi, 2014).

The application of nanotechnology in agriculture has the potential to revolutionise the sector by introducing novel techniques for quick disease detection, and targeted treatment, increasing the potential of vegetation for retaining nutrients, combating pathogens, coping with environmental stresses, active operational handling schemes, etc. Agronomic production will be boosted by advanced sensors and smart delivery systems to defeat pathogens and avoid future harvest problems. Another advantage of nanotechnology is to enhance the agronomic yield through genetic modification in variety as well as enable the introduction of genes and pesticides to precise sites at the cellular level. It additionally makes it feasible to develop a new generation of agrochemicals with the objective of minimising adverse environmental impacts while maintaining agricultural yields (Dasgupta and Bachaspati, 2022). Applying nano fertilizers reduces the toxic effects of fertilisers applied in higher amounts in the soil. By lessening the competition for nutrients between weeds and plants, nano herbicides may boost crop yield without damaging the agricultural land. Recent studies on nano phosphor-based electroluminescence lighting devices have demonstrated that their use may substantially decrease energy consumption. Such nanotechnology-based lighting could reduce energy costs and promote photosynthesis in hydroponic indoor farming. Agriculture products can be delivered to the targeted areas using nanoscale carriers without degrading them or allowing them to be diluted by chemical runoff. By gathering the necessary information from the cultivated fields, nano-sensors and devices can be employed for real-time monitoring in precision agriculture. The potential uses of nanotechnology in agricultural science have an optimistic outlook and can be an enormous source of innovation for increasing yields and considerably advancing the farming techniques employed within precision agriculture (Worrall *et al*., 2018).

Mechanism of nanoparticles

Antimicrobial characteristics of nanoparticles are frequently attributed to a variety of mechanisms, including metal ion release, non-oxidative processes, oxidative stress and cell death. However various researchers contend that their modes of action can differ and depend on multiple mechanisms (Lemire *et al*., 2013). They are as follows;

- The permeability of the plasma membrane is compromised and impeded from functioning correctly by the attachment of the sulphur groups of proteins to nanoparticles.
- DNA damage.
- Electron transport chain interruption and protein oxidation.
- Cellular damage may result from the generation of reactive oxygen species (ROS).
- A barrier to nutrient absorption.

All of the aforementioned processes interact with one another and work collaboratively to counteract phytopathogens. According to Ghormade *et al.*, (2011), nanoparticles may be particularly target-specific in the treatment of diseases and enhancement of crop plants. The surface-to-volume ratio of the nanoparticle is inversely correlated with both its reactivity and biological activity (Dubchak *et al*., 2010). Encapsulating active substances allows for targeted and gradual distribution while preventing leaching and runoff (Gruère, 2012).

Commonly used nanoparticles for plant disease management

The use of nanoparticles to improve antimicrobial effectiveness has been the focus of many studies. This sparked the formation of many forms of nanomaterials, which were then divided into inorganic (metallic nanoparticles such as Ag, Cu, O and TiO_2), organic (liposomes), carbon-based (Carbon Nano Tubes) and composite-based nanoparticles. Metallic nanoparticles, which have exceptional physical and chemical abilities, are rapidly gaining acceptance as potent, environmentally acceptable and secure substitutes for synthetic fungicides. They have outstanding potential to eradicate certain microorganisms from soil, hydroponics and plants. Silver, silica, gold, zinc, and copper-based metallic nanoparticles are the most popular in the market.

Silver nanoparticles

Silver nanoparticles have been used for the first time in agriculture to combat plant diseases. It exhibited an ability to kill plant diseases and had broad-spectrum antimicrobial activity in both ionic and nano forms. Silver nanoparticles have shown great efficacy against fungal phytopathogens like *Rhizoctonia solani*, *Sclerotinia sclerotiorum* and *Sclerotinia minor* that have a significant negative economic impact on plants (Jo *et al*., 2009). Specifically, *Alternaria alternata*, *Penicillium digitatum* and *Alternaria citri* are susceptible to the effects of silver nanoparticles against citrus fruit fungal pathogens. Nanosilver colloids exhibit antifungal action against the rose powdery mildew-causing *Sphaerotheca pannosa* var. *rosea*. Kim *et al*., (2009) assessed Ag nanoparticles' effectiveness against *Raffaelea* sp., which causes oak wilt disease.

Gold Nanoparticles

The gold nanoparticles possess antibacterial effects on *Pseudomonas* spp. Currently, diagnostic applications for gold nanoparticles are popular. The development of new biosensors for the detection of harmful microbes, such as DNA-gold nanoparticle probes, appears promising. In order to stabilise them against aggregation and maintain their pink tint, the method includes hybridising gold nanoparticle-oligonucleotide probes with complementary DNA. The absence of complementary DNA causes aggregation, which causes the solution to appear purple. In a bid to make it easy to visually identify antibodies attached to pesticide residues, gold nanoparticles' ability to produce colour was utilised in pesticide detection. The nano-silversilica compound has a substantial antimicrobial impact against plant pathogens such as *Phytophthora* spp., *Rhizoctonia* spp., *Colletotrichum* spp., *Botrytis* spp., *Magnaporthe* spp., and *Pythium* spp. (Park *et al*., 2006). These composites provide long-term control without being harmful and may be used to combat resistant phytopathogens.

Copper Nanoparticles

They can destroy the cellular structure of bacteria and fungi by causing an effect akin to that of fungicides and hydroxyl radicals. Nanosized copper was successful in preventing mung bean leaf spot disease and rice bacterial blight (Gogoi *et al*., 2009). Application of insecticides and fertilisers with nano Cu formulations promotes plant disease resistance. There are reports that the disease caused by *Colletotrichum capsici* can be alleviated using copper nanoparticles synthesised from Eucalyptus and Mint. Similarly, Giannousi *et al*. (2013) discovered that Cu-based nanoparticles (Cu_2O, CuO and Cu/Cu_2O) were safer for the plants and more effective against *Phytophthora infestans* on tomatoes when compared to registered marketed commercial copper-based products. They also exhibited antibacterial activity against *Bacillus subtilis, E. coli, S. aureus, and P. aeruginosa*. The nematodes *Xiphinema index*, which infects grape plants, can be controlled by a Bordeaux combination which comprised of Cu NP (Elmer and White, 2018).

Zinc nanoparticles

It acts as a nanofungicide, releasing hydroxyl and superoxide radicals which degrade fungal cell walls and hyphae, hinder conidial growth and result in cellular death (Patra *et al*., 2012). ZnO is generally utilised as a micronutrient fertiliser in agriculture, but it also has well-known antibacterial effects. Micronutrients like Mn (manganese) and Zn (zinc) particles prevented *Helianthus annuus* from developing damping off and charcoal rot diseases. The growth of *Aspergillus flavus* can also be stopped by the Zn nanoparticles (Jayaseelan *et al*., 2012). These nanoparticles have been demonstrated to be more beneficial than synthetic fungicides as antifungal agents. Citrus canker disease caused by the *Xanthomonas compestries* pv. *citri* was suppressed by the application of Zinckicide, a nano Zn formulation (Graham *et al*., 2016).

Chitosan nanoparticle

As chitosan is less harmful, biodegradable and affordable, it has recently drawn a lot of interest. A recent study showed that the plant developed disease resistance as a result of the application of chitosan nanoparticles. Due to the ease of production, it is a valuable carrier for drug delivery and gene transfer. By increasing defence-related enzymes such as polyphenol oxidase, phenylalanine ammonia-lyase and -1,3-glucanase, the application of chitosan nanoparticles increased disease resistance in the tea plant (Chandra *et al*., 2015). It can also boost a plant's immune response, suggesting that they are a novel and prospective therapeutic treatment for treating plant diseases. *In vitro*, tests revealed that chitosan nanoparticles have antifungal properties and may shield finger millet plants from the blast disease caused *Pyricularia grisea*. *Fusarium oxysporum* and *Pseudomonas capsici* and *Xanthomonas compestris* that damage tomatoes have been successfully combated by chitosan nanoparticles. There is very little knowledge concerning the management of plant diseases that are related to non-metals, metalloids and metallic oxides. Nevertheless, several data support the ability of these nanoparticles to resist disease. The most studied non-metal nanoparticles are nano S (sulphur) and nano Ti (titanium). The majority of nano fungicide formulations use nano sulphur. Sulphur nanoparticles had been shown to be effective against fungal diseases caused by *Fusarium solani, F. oxysporum, Aspergillus niger* and *Venturia inaequalis* (Rao and Paria 2013). Nano Ti is employed as a potential antifungal agent because of its autocatalytic properties. Metalloid Si nanoparticles have a number of effects on the treatment of diseases. Powdery mildew was prevented when nano Si and Ag were applied. Si has many impacts on plant disease management when applied in ions, according to several scientific researches. A metallic oxide nanoparticle called Nano MnO is used to treat the wilt disease that affects watermelons and eggplants (Elmer and White, 2016). Other metallic oxide nanoparticles that have applications in plant pathology include CuO, TiO_2, Fe_2O_3, and MgO.

Conclusion

Nanotechnology has the ability to revolutionise the current technology employed in disease management and provide solutions for agricultural applications. It will be crucial in the development of numerous new techniques for enhancing plant health through the use of disease diagnostics, disease control, etc. When pesticides are loaded onto nanoparticles, their bioavailability and efficacy increase, toxicity is decreased, shelf life is extended and active ingredients are delivered in a regulated manner. By using fewer pesticides, nanotechnology serves as an optimistic outlook for managing plant diseases sustainably. It is anticipated that multidisciplinary and collaborative research will offer a solid foundation for the implementation of nanotechnology applications for plant protection. This innovative study transformed the green revolution into the green nano-bio-revolution. It is still in its infancy and has only just been investigated in the domain of plant pathology to manage, diagnose plant diseases.

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