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Silver Nanoparticles in Fungal Plant Pathogen Management

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ABSTRACT

Fungal plant pathogens are a major threat to global agriculture, contributing to significant crop losses worldwide. The management of fungal pathogens is needed for the security of agricultural products against the diseases caused by them. Present efforts are focused on searching for the non-chemical and effective methods of plant disease management which will not pose any damage to the environment nor does it cause any kind of imbalance in the existing biota. In order to overcome this problem, nanoparticles can be used as an alternative strategy for controlling the plant pathogens due to their effectiveness and environmental-friendly nature. It enables the development of innovative strategies for the control of fungal pathogens that can significantly affect crop yields. Silver nanoparticles (Ag NPs) are considered to be the most prominent and effective nanoparticles incorporated with widespread applications, on account of their distinctive characteristics. Hence, they can be employed for effective and eco-friendly disease management, making them an attractive option for managing the plant diseases safely. Besides, being acting as a

nanofungicide, it also acts as nanofertilizer enhancing the seed germination as well as plant growth and has the potential to boost the plant metabolism.

INTRODUCTION

Nowadays, nanotechnology has shown immense potential in revolutionizing agriculture, particularly in the management of fungal plant diseases and enhancing overall agricultural productivity. Plant pathogens cause significant decline in crop production worldwide with 20-40% of estimated losses each year (Worrall *et al.,* 2018; Shahid *et al.,* 2023). The diseases are mainly caused by fungi, bacteria, viruses etc. of which fungal diseases causes heavy yield losses to the agriculturally important crops (Shahid, 2023). Generally, farmers use chemicals to manage the plant diseases to some extent but on the other hand these chemicals cause hazardous effects on environment and human (Shahid and Khan, 2016; 2019). Concerns about the potential toxic effects of agricultural chemicals on non-target organisms, their environmental impacts, as well as regulatory challenges highlight the need for thorough research and impact assessments.

Nanoparticles are small particles at nanoscale level in the range of 1-100 nanometres (nm) in diameter. They are the tiny particles which are too small to be seen by the naked eye. This nanometre scale is very crucial as the properties of the materials can change dramatically at such a small scale. Transmission micrograph image of silver nanoparticles has been shown in figure 1.

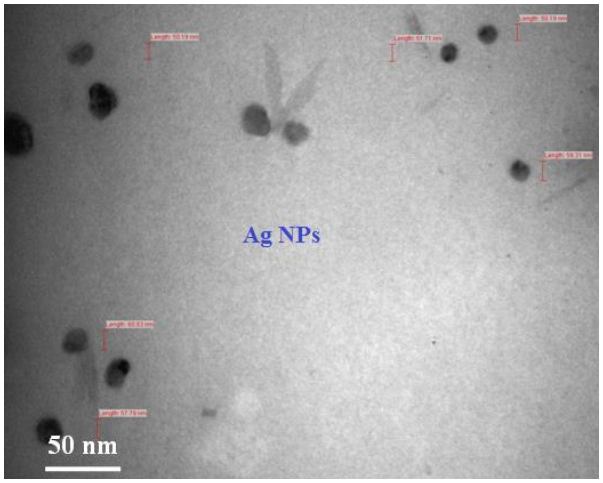

Figure 1. Transmission electron microscopic (TEM) image of silver nanoparticles

Silver nanoparticles (Ag NPs) have numerous applications in plant pathogen management and play an important role in agriculture that are essential for improving crop production ultimately ensuring the food security (Figure 2). Silver nanoparticles garnered significant attention in the agriculture sector because of their broad-spectrum antifungal properties, which make them highly effective against a wide range of fungal plant pathogens. During recent years, a lot of interest has been shown by researchers on the use of silver nanoparticles in agriculture. In addition to acting as nanofungicide for the control of the plant diseases, silver nanoparticles can also be used as nanofertilizer to promote the plant growth. They can also be utilized in the form of 'nano-packages' which helps in increasing the shelf-life of fresh agricultural products.

Figure 2. Applications of silver nanoparticles in plant pathogen management

SILVER NANOPARTICLES AGAINST FUNGAL PLANT PATHOGENS

Nanotechnology has recently emerged as an excellent option for controlling the plant diseases that poses huge agricultural yield losses (Shahid et al., 2024). Agricultural production is declining worldwide each year by plant diseases due to which the economic impact is enormous, with some estimates suggesting that plant diseases cause losses worth billions of dollars annually. In response to these losses, substantial investments have been made in different strategies to control as well as mitigate the effects of these plant diseases. During recent years, nanoparticles have attracted the focus of many scientists working in the agricultural sector for their use in plant disease suppression because of their unique properties (El-Khawaga *et al.,* 2024). It has been observed that silver nanoparticles have a distinctive role against a wide range of microorganisms, including fungi, bacteria, viruses etc. that infect and damage plants.

Nanoparticles have shown significant potential inhibiting the growth of harmful fungi by saturating and getting stick to the fungal hyphal surface. The surface of fungal hyphae which are long, thread-like structures and that make up the body of fungi is often rich in certain biological molecules, like chitin and proteins, which can interact with nanoparticles. Biologically synthesized nanoparticles (bio-nanoparticles/biogenic nanoparticles) can have higher antifungal efficacy, and this can be attributed to numerous factors tied to their unique properties as well as the mechanisms by which they interact with the fungi.

Silver nanoparticles (Ag NPs) are one of the most commonly studied and effective nanoparticles which have been used to manage a large number of plant pathogens causing significantly important plant diseases. In fact, silver was the first nanoparticle to be studied for the management of plant diseases. Kim et al. (2008) explored the early use of silver nanoparticles for the management of powdery mildew disease in roses. Besides this, numerous reports are there which shows that Ag NPs exhibited potent antifungal activity against several fungal plant pathogens such as *Fusarium oxysporum, Rhizoctonia solani, Macrophomina phaseolina, Alternaria*

alternata, Curvularia lunata, Colletotrichum gloeosporioides, Magnaporthe oryzae, Bipolaris sorokiniana, Sclerotinia minor etc. (Tariq *et al.,* 2022; Ibrahim *et al.,* 2024).

The antifungal efficacy of silver nanoparticles is being explored very extensively due to high antifungal activity of silver nanoparticles against plant pathogenic fungi. Silver is extensively known to attack a wide range of biological processes in the microorganisms that includes change in the cell membrane structure as well as functions. Ag NPs causes extensive damage to the fungal hyphal wall and cell membrane that ultimately causes hyphal death. Hence, using nano-sized Ag particles as antifungal agents have become more advantageous in today's world as technological advances has made the production of nanoparticles more economical. Many fungi have the ability to form biofilms. Plant-associated fungal biofilms are usually supposed to configure relations across and among plant populations. Silver nanoparticles are well known for their strong anti-biofilm activity which opens the research avenues for plant disease management programs (Motaung *et al.,* 2020). Because of the exceedingly small scale of silver nanoparticles, these possess high reactivity, tiny areas, as well as rapid penetration of the biofilm materials and cell membranes with high surface area to volume ratio.

The efficacy of silver nanoparticles as antifungal agents is influenced by various factors, including their physical properties (size, shape, surface charge, and coating agents) and the specific characteristics of the pathogens they target. It has been reported that some fungal pathogens are more prone to silver nanoparticles as compared to other nanoparticles. In the recent years, silver nanoparticles have been emerged as highly fascinating and have more market value in comparison to other nanoparticles due to their distinctive properties and widespread use across various industries (Parveen *et al.,* 2022). The main factors driving the popularity of Ag NPs in both research as well as consumer products include their antifungal properties, ease of synthesis, and potential for varied applications in different fields. Because of the broad spectrum antifungal efficacies, silver nanoparticles have the vision to improve plant protection, plant disease detection, as well as plant growth monitoring, which can result into increased global food production with superior quality in order to achieve sustainable development of agriculture (Prasad *et al.,* 2017).

CONCLUSION

Nanotechnology is considered as the most advanced, novel as well as fast developing field of science and technology. Silver nanoparticles are one of the most commonly used nanoparticles in the area of agricultural research. Because of their unique properties and strong antifungal efficacy, they are used to control a wide variety of plant pathogens especially fungal pathogens. Nanoparticles exhibit enhanced characteristics over conventional agrochemicals such as stability, toxicity reduction, solubility, bioavailability, thermo-tolerance etc. hence, it is better to use the nano-form of the materials as compared to the conventional bulk materials as it reduces the chemical input in the agriculture and prevent the agro-system from harmful contaminants. This is why nanotechnology is such an exciting and diverse field, with continuous progresses and new uses evolving across a variety of agri-industries. The research landscape for nanotechnology in plant pathogen management is highly promising, because the opportunities offered by nanoparticles for the development of efficient and reliable products for the control of plant pathogens are being actively explored.

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CONFLICT OF INTEREST

All the authors declare no conflict of interest.

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