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Review Article

Silver nanoparticles: magic bullets of agriculture

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Abstract

Silver nanoparticles have well-evolved as antimicrobial agents and a nano-drug carrier with enormous success in the field of medicine. The particles act as magic bullets that carry the active ingredient along with it, prompting the synergistic outcomes with dual functionary. The particles are also setting up in the field of agriculture and are supposed to bring a new era of agrochemicals. A lot of work has been done and significant work is under the process, but no compilation about the impact of the work is done to give a better vision. Thus, the present article was designed to give an insight into the applications of modified and unmodified silver nanoparticles in agriculture.

Keywords agriculture, antimicrobial, bio-efficacy, nanoparticles, silver

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Introduction

Nanotechnology gives an effective and green convention for creating more up-to-date and regenerative medications and agrochemicals in nano-shape to combat the various problems related to uncontrolled utilization and toxicology of the bioactive specialists [1-9]. The efficacy of these nano-architectural systems was attributed to their improved morpho-topological and physico-chemical properties [10], making them enact differently from their bulk counterparts [11]. There is potential to change the whole situation of the current agricultural practices with involvement of nano-pesticides. Nano-agrochemicals refer to the nano-pesticides that include the utilization of either little particles of pesticidal active ingredient or other little engineered structures with loaded pesticidal active ingredient that may prompt controlled release of the active molecule and appropriate assimilation of the mixture into the plants [12-15] and anticipation of undesirable pesticide development [16]. These formulations degrade faster in the soil and gradually in plants with residue levels beneath the administrative criteria in foodstuffs [17].
Among the designed nanostructures, the usage of metal nanoparticles is one of the leading decisions and the surface alteration of metal nanoparticles by loading and coating prompts an expanded capability of the bioactive agents. The dual benefit of these surface modified nanoparticles involves the stabilization of individual nanoparticles along with the steric repulsion between the particles that inhibits agglomeration keeping the nanoparticles intact [18].

Among various metal nanoparticles of biological significance, silver nanoparticles are referred as magic bullet, which are considered to act as an astounding biological agent as well as a good delivery system [19], showing the site-specific activity, hypo-toxicity [20, 21] and ecofriendly anti-microbial action [22]. Furthermore, there use in much smaller concentration [23] for antimicrobial effect provides enormous hope in combating pathogens in the field of medicine and agriculture [24-26]. There are more than 100 pesticides that contains Ag due to its anti-microbial properties [16]. Furthermore, development of resistance towards AgNPs has not yet been reported favoring its use in modified and unmodified forms as a solution to many agricultural problems [20].

Antimicrobial Potential

Management of fungal diseases of food crops is of great economic importance. Extraordinary endeavors has been made for the development of safe management methods that pose less danger to humans and animals, with a focus on overcoming deficits of synthetic fungicides. The strong bio-efficacy of AgNPs encouraged the agro-scientists to explore the particles for their potential against the various plant pathogenic diseases. The work in the field was reviewed and compiled to get a better understanding of the past inputs.

Jo et al., [27] tested various forms of silver ions and nanoparticles for their antifungal action on two plant-pathogenic fungi, *Bipolaris sorokiniana* and *Magnaporthe grisea*. *In vitro* petri dish assays made by him indicated that silver ions and nanoparticles had a significant effect on the colony formation of these two pathogens. Effective concentrations of the silver compounds inhibiting colony formation by 50% (EC_{50}) were higher for *B. sorokiniana* than for *M. grisea*. The *in vitro* and *in planta* studies of silver ions and nanoparticles indicated that they influence colony formation of spores and disease progress of plant-pathogenic fungi. *In planta* efficiency of silver ions and nanoparticles is strong enough with preventive action, that is attributed to the direct contact of silver with spores and germ tubes, and inhibit their viability.

Kim et al., [28] made an exploration concerned with the fungicidal properties of nano-size silver colloidal solution (WA-CV-WA13B, WA-AT-WB13R, and WA-PR-WB13R) as an agent for antifungal treatment of various plant pathogens at different concentrations of 10, 25, 50, and 100 ppm. Eighteen diverse plant pathogenic fungi were treated with these AgNPs on potato dextrose agar (PDA), malt extract agar, and corn meal agar plates. The outcomes demonstrated that AgNPs possess antifungal properties against these plant pathogens at various levels. Treatment with WA-CV-WB13R AgNPs resulted in maximum inhibition of most fungi with most significant effect observed on PDA at concentration of 100 ppm.

Ocsoy et al., [29] described the use of DNA-directed silver (Ag) nanoparticles (NPs) developed on graphene oxide (GO) that was found to lessen *X. perforans* cell viability in culture and on plants. The Ag@dsDNA@GO composites specify magnificent antibacterial ability in culture with pointedly improved stability, and robust adsorption properties at very low concentration of 16 ppm. Application of Ag@dsDNA@GO at 100 ppm on tomato transplants in a greenhouse experiment significantly diminished the severity of bacterial spot disease compared to untreated plants, with no phytotoxicity.

In another study, Babu et al., [30] focused on the applications of *in vitro* biosynthesized silver nanoparticles using marine bacteria *Shewanella* algae bangaramma in the laboratory. The particles were found to have both larvicidal and bactericidal activities. The maximum LC_{50} and LC_{90} values with 95% confidential limit (4.529 mg/ml (2.478 - 5.911), 9.580 mg/ml (7.528-14.541) were observed with III-instar larvae of *Lepidiotamansueta* (Burmeister). And the order of bactericidal activity against marine fouling bacteria is found to be *Pseudomonas sp.* < *Vibrio cholera* < *Roseobacter sp.* < *Alteromonas sp*.

Narayanan and Park [31] reported the synthesis of metal nanoparticles using turnip leaf extract and further investigated its interaction with wood-degrading fungal pathogens such as *Gloeophyllum abietinum, G. trabeum, Chaetomium globosum*, and *Phanero chaetesordida*. The nanoparticles showed broad spectrum antifungal activity against wood-degrading fungi by inhibiting growth and thus, the greener-synthesized nanoparticles were found to be effective antifungal agent against wood-degrading fungal pathogens.

Spherical shaped silver nanoparticles using culture supernatant of *Serratia sp*. BHU-S4 were prepared and evaluated for their effective application for the management of spot blotch disease in wheat [32].

Mahdizadeh et al., [33] evaluated the *in vitro* antifungal activity of silver nanoparticles, at concentrations of 6, 8, 10, 12, 14 and 16 ppm, on five phytopathogenic fungi by calculating the inhibition of radial fungal growth and mycelial growth. The most sensitive fungus to nanoparticles was *Pythium aphanidermatum*, as all tested concentrations showed 100% inhibition during the 10 days of observation followed by *Sclerotinia sclerotiorum*, since it was able to grow only at concentration of 6 ppm followed by

M. phaseolina as its growth was inhibited under all the concentrations after three days. Further, the study was made to understand the effect of silver nanoparticle at 6 ppm (optimum concentration) on *Macrophomina phaseolina* in greenhouse. Five treatments were given in green house experiment, that includes no nanosilver-no pathogen (Negative control), no nanosilver + pathogen (Positive control), 6 ppm nanosilver– no pathogen, 6 ppm nanosilver + pathogen, Carboxin-Thiram (0.15%) + pathogen. Four characteristics related to the shoot and root fresh weights and dry weights were noted. The overall results indicated that the treatments with nanosilver and fungicide gave higher yields than the positive control. The chemical control treatment had the highest measured parameters, while 6 ppm nanosilver + pathogen treatment had the same parameters as negative control. Overall conclusion made was to use nanosilver as a safer alternative to chemical fungicides for control of *M. phaseolina*.

Xia et al., [34] aimed at evaluating the antifungal properties of silver nanoparticles against the pathogenic fungus *Trichosporona sahii*. It had a significant inhibitory effect on the growth of *T. asahii* with minimum inhibitory concentration (0.5 mg/mL), which was lower than amphotericin B, 5-flucytosine, caspofungin, terbinafine, fluconazole, and itraconazole and higher than voriconazole. Silver nanoparticles damaged the cell wall, cell membrane, mitochondria, chromatin, and ribosome. They concluded that silver nanoparticles have good antifungal activity against the test fungus and based on electron microscopy observations this activity was attributed to the permeation of AgNPs in the fungal cell and damaging the cell wall and cellular components.

Studies of silver against six different *Rhizoctonia solani* anastomosis groups (AGs) infecting cotton plants treated with plant pathogenic fungi using the nanoparticles at concentrations of 0.0, 0.0002, 0.0005, 0.0007, 0.0009, 0.0014 and 0.0019 mol/L showed that AgNPs have antifungal properties to control *R. solani* AGs [35].

The other development in the field involved the use of novel nano-bioconjugate of silver and cysteine as potential anti-mycobacterial agents. The cysteine capped AgNPs were prepared from silver nitrate by reduction of sodium borohydride and cysteine as a capping agent. The so-prepared Cys bound silver nano-particles (17 ppm Ag in Cys) enhanced the anti-mycobacterial activity of cysteine from 10 ppm to about 6 ppm encouraging the exploitation of various other bio-active agents as capping agent with their enhanced activity [36]. The synthesis of bioactive silver capped nano-conjugates with 5-Amino-β-resorcylic acid hydrochloride dehydrate (AR) were also reported. These nano-conjugates also showed significantly enhanced biological activity in comparison to free drug molecules. *In vitro* antimicrobial (antibacterial, antifungal), enzyme inhibition (xanthine oxidase, urease, carbonic anhydrase, α-chymotrypsin, cholinesterase) and antioxidant activities of the created nanoparticles were researched on conjugation to silver metal [37].

Ali et al., [38] evaluated the possibilities of using silver nanoparticles (AgNPs) to control the land snail. The AgNPs have been produced biologically using white radish (*Raphanus sativus* var. *aegyptiacus*). The disclosure of the snails and soil matrix to AgNPs in a laboratory experiment diminished the activity and the sustainability of the land snail (20% of AgNPs treated snails died). The investigation was clarified to look at the reappearance of contagious populace in the surrounding soil. The synergistic effect of synthesized AgNPs as antifungals evidently discovered that AgNPs can be efficiently used against several plant pathogenic fungi. The existing study results can be explored further as a new avenue to use the snail as bio-indicator organism of environmental pollution.

Effect on germination

Effect of silver nanoparticles on seeds of Fenugreek (*Trigonellafoenum graecum*) has been evaluated. Different concentrations of silver nanoparticles (0, 10, 20, 30 and 40 μg mL^{-1}) were used and results showed that maximum seed germination (76.11%), speed of germination (4.102), root length (76.94 mm), root fresh weight (2.783) and root dry weight (1.204) were obtained at a concentration of 10 μg mL^{-1}. These outcomes demonstrated that the use of silver nanoparticles could be utilized to fundamentally improve seed germination potential, mean germination time, seed germination record, seed vigor index, seedling fresh weight and dry weight [39].

The impact of silver nanoparticles (AgNPs) on the growth of three different crop species viz. wheat (*Triticum aestivum*, var. UP2338), cowpea (*Vignasinensis*, var. Pusa Komal), and *Brassica* (*Brassica juncea*, var. Pusa Jai Kisan), beside their influence on the rhizospheric bacterial diversity was examined at three different concentrations (0, 50 and 75 ppm) through foliar spray. After harvest, shoot and root parameters were compared, and it was detected that wheat was relatively unaffected by all AgNP treatments. The model growth promotion and increased root nodulation was observed at 50 ppm treatment in cowpea, while greater shoot parameters were verified at 75 ppm in *Brassica*. To screen the influence of AgNPs on soil bacterial community, sampling was performed from the rhizosphere of these crops at 20 and 40 days after the spraying of AgNPS. The bacterial diversity of these samples was analyzed by both cultural and molecular techniques (denaturing gradient gel electrophoresis). It was apparent from the results that application of AgNPs changes the soil bacterial diversity and this is further affected by the plant species grown in that soil. Moreover, the functional bacterial diversity varied with different concentrations of AgNPs [40].

Insecticidal activity

The work by Rouhani et al., [41] included the assessment of the insecticidal activity of Ag and Ag-Zn nanoparticles prepared by solvo-thermal technique, against the *Aphis nerii*, the oleander aphid which is the reason for the mortality of a large number of oleander (*Nerium oleander* L.) shrubs every year. The LC50 value for Ag and Ag-Zn nanoparticles were found to be 424.67 mg mL-1, and 539.46 mg mL-1, respectively. The outcome indicated that Ag nanoparticles can be used as a profitable tool in pest management programs of *A. nerii*. One evident advantage of utilizing them as insecticides is the low risk of developing resistance by the insects in long term usages.

Conclusion

The review on silver nanoparticles indicated its pronounced importance in field of agriculture with major focus on its antimicrobial activity along with the little deviation towards understanding its impact on germination and insecticidal properties. Further exploration to produce the effective and newer outcomes is required.

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