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Brief overview of the application of silver nanoparticles to improve growth of crop plants

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Abstract: With the advancement in nanotechnology, nanoparticles are reported to have applications in various fields. Their positive role in the environment, especially in plant ecosystem, is extensively studied nowadays. Among the metal nanoparticles, the silver nanoparticles (AgNP) are receiving special attention because of their ability to increase the growth and yield in many crops. Although many studies are found containing toxic effects of AgNPs the perspective of the present review is to collect the information about their positive role in growth and yield enhancement of crops. During this brief overview, many important crop plants are found to have a positive response towards the application of AgNPs. The appropriate elucidation of physiological, biochemical and molecular mechanism of nanoparticles in plant leads to better plant growth and development. It is concluded from this review that cautious and sensible use of nanotechnology can warrant food security through boosting agricultural production.

1 Introduction

Recently, research in nanotechnology has gotten a lot of attention because of its applications and beneficial uses. Nanoparticles, size ranges from 1 to 100 nm, have been widely used in various fields of bioscience and biomedicine with an increasing number of commercials [1]. In addition to these, nanotechnology is also making its influence in the field of agriculture. Nanotechnology is establishing as a growing field of science because of its potential to transform our agriculture and to advance the conditions of the poor. Nanotechnology is improving agricultural yields for mushrooming population in Asian countries. It has potential to provide food security by enhancing crop production through precision farming, efficient utilisation of water, protection against insects and diseases. It is continuing to provide new tools and materials for molecular biology and pathogen detection and is also playing a role in the protection of the environment. Nanoscience is proven as one of the important tools in the modern era of agriculture and agri-food nanotechnology. It is predicted to become a driving force for economic revolution in the near future. The focus of the agri-food technology is for sustainable utilisation and safety of agriculturally grown foods including the production of crops for human and animal feeding.

Nanoparticles have both growth promoting and harmful effects on crops. Uses of nanoparticles in crop sciences are consistently increasing. It is observed that foliar application of nanomaterial as fertiliser boosts the agriculture production [2]. Various types of nanoparticles, particularly metal and carbon nanoparticles, have been explored for their absorption, accumulation, translocation and especially, for their influence on the growth and development of a wide variety of agricultural plants [3, 4]. The positive morphological impacts of nanoparticles have been recorded in many crop cultivars such as wheat, soybean, radish, alfalfa, onion, corn, rape, lettuce, cucumber, watermelon, spinach and tomato in terms of enhancing the seed germination rate, germination percentage, root and soot lengths, and fresh and dry weight. Similarly, nanomaterials have also improved the chlorophyll contents, carotenoids and nitrogen metabolism in some crops including peanut, soybean and spinach [5–9].

Among all the nanoparticles, silver nanoparticles (AgNPs) have remarkable uses in crop production. The uptake and accumulation of nanoparticles were found in plants when grown in a nutrient medium containing nanosilver [10]. Application of nanoparticles improved agronomic traits of soybean [11]. It is observed that when the seeds of cotton were soaked in AgNPs prior to germination, AgNPs produced advantageous effects [12]. AgNPs also have strong antimicrobial effects [13]. They can control and avoid plant diseases. These particles in concentrations of 0.5–1000 ppm caused the faster growth of plants and controlled pathogens [14]. AgNPs are beneficial for seed growth and germination [15] and act as growth stimulators [16]. They can enable plants to inhibit senescence caused by reactive oxygen species (ROS) as a result of oxidative stress. Senescence induced by oxidative stress and ROS generation triggered by 2,4-D in mungbean was repressed by application of 100 μl of AgNPs [17]. Thus keeping in view the importance of AgNPs, the data about their positive effect on crop plants is collected and presented in the brief overview form.

2 AgNPs and plant growth

The application of AgNPs in pharmaceuticals and medical is very focused and promoted area of research. However, application of AgNPs in agriculture is recent. Besides other remarkable applications of AgNPs such as antimicrobial and drug delivery, recent studies explored their role in the improvement of growth of many crop plants.

The available literature shows that a large number of studies have been carried out on the application of AgNPs as antimicrobial and cytotoxic, however, only a few number of studies were done on an application of AgNPs on plants [18, 19].

2.1 Studies where AgNPs showed a toxic effect

There are many studies where AgNPs showed toxicity to a great extent. They produced a negative impact on seedling growth by reducing plant biomass and root elongation. They also caused morphological modifications such as reduction in the stem and shoot size. They interrupt replication of DNA and effect gene expression by producing ROS. The toxic effect of AgNPs on plants is shown in Table 1.

2.2 Studies where AgNPs showed a positive effect

The positive effect of AgNPs on different plant species is shown in Table 2. Study of Krishnaraj *et al.* [19] reveals a significant effect of biosynthesised AgNPs on seed germination of *Bacopa monnieri*, induced the synthesis of important metabolites like carbohydrate

Table 1 Studies where AgNPs showed toxic effect

Plants (cultivars)	Ag nanoparticles (shape, size, conc.)	Findings	Reference
Triticum aestivum	10 nm, 0–5 mg/kg	root and shoot lengths reduced	[20]
Arabidopsis thaliana	5 and 10 nm, 1 ppm	inhibited the root growth	[21]
Populus deltoides nigra	25 nm, 100 ppm	decreased in biomass	[21]
Cucurbita pepo	<100 nm, 500 ppm	reduction in transcription and biomass	[22]
Lolium perenne, Linum usitatissimum, Hordeum vulgare	0.6–2 nm (colloidal), 10 and 20 ppm	reduction in seed germination rate, percentage and shoot length	[23]
Vicia faba	60 nm, 12.5, 25, 50 and 100 ppm	chromosomal aberrations	[24]
Lolium multiflorum	6 nm, 1–40 ppm	declined in biomass and root length	[25]
Allium cepa	70 nm, 0–80 ppm	DNA damage, cell wall disruption	[26]
Oryza sativa	1000 ppm	cell wall breakage	[27]
tomato	<100 nm	decrease in chlorophyll, Genotoxicity	[28]
Lemna gibba	50 nm, spherical, 0–10 ppm	frond number decreased	[29]
Raphanus sativus	1–10 nm, 0, 125, 250 and 500 ppm	reduction in seed germination, seedling growth and nutrient	[30]
Triticum aestivum	10 and 100 mg/l	Fresh and dry weight of roots and shoots decreased. Totally chlorophyll, carotenoids and protein content also decreased.	[31]
Triticum aestivum	10 mg/l	decreased seedling growth and modified root tip cells	[32]
Nicotiana tabacum	1–100 nm	chloroplast size changed	[33]

and protein and reduced the amount of phenols, catalase and peroxidase activities. Application of biologically synthesised AgNPs on *Boswellia ovaliofoliolata* enhanced seed germination and seedling growth [34]. The studies of Salama [35] and Sharma *et al.* [36] show that application of AgNPs improved plant growth parameters including length of root and shoot and leaf area and biochemicals including chlorophyll, carbohydrate, protein and antioxidant enzymes in *Brassica juncea*, *Phaseolus vulgaris* and *Zea mays*. However, Gruyer *et al.* [37] suggested both positive and negative effects of AgNPs on the growth of roots, depending upon the type of plant species. They reported an increase in the length of root in barley plant but decrease in lettuce. In an another study, the effect of AgNPs on the rate of seed germination in 11 wetland plants including *Carex lurida*, *C. scoparia*, *C. vulpinoidea*, *C. crinita*, *Lolium multiflorum*, *Panicum virgatum, Eupatorium fistulosum*, *Scirpus cyperinus*, *Phytolaca americana*, *Juncus effusus* and *Lobelia cardinalis* was studied and increase in germination rate was found only in *E. fistulosum* [55]. The study of Rezvani *et al.* [38] shows that AgNPs enhanced root growth in *Crocus sativus.* They suggested that AgNPs improve growth by blocking the action of ethylene. Some studies suggested that the impact of AgNPs on morphological and physiological aspects of plants related to the morphology of nanoparticles used. Syu *et al.* [39] reported the effect of AgNPs with three different morphologies (triangular, spherical and decahedral) on molecular and physiological responses of *Arabidopsis.* Their findings suggested that the decahedral AgNPs have the highest degree of potential to promote the root growth. On the other hand, spherical AgNPs did not show any effect on root elongation but they were involved in the accumulation of the highest level of anthocyanin in seedlings. The life of *Asparagus* leaves extended from 2 to 21 days when they were applied with AgNPs with a higher amount of chlorophyll, ascorbate and fibres opposed to untreated leaves [40]. Jasim *et al.* [41] reported that fenugreek seedlings (*Trigonella foenum-graecum* L.) after treated with AgNPs have shown significant enhancement in leaf number, root and shoot length and fresh weight. A 23% increase in diosgenin (chief phytochemical of fenugreek) was also reported with the application of AgNPs.

In addition to the morphology, the concentration of applied AgNPs also plays an important role. It is found that 50 ppm AgNPs increased plant height, fresh and dry weight, length of root and shoot of *Vigna radiata* [42], fresh weight, root and shoot lengths, and vigor index and chlorophyll contents of seedlings of *Brassica juncea* [36], total chlorophyll, chl-a, chl-b, root FW in *Glycine max* plants [15]. Similarly, different concentrations of AgNPs (0, 10, 20, 30 and 40 μg/ml) were applied to examine their effect on growth parameters of fenugreek and it was observed that low concentration of AgNPs promoted seed germination and early growth opposed to control while higher concentration reduced the rate of seed germination and growth [43]. Dose depended effect of AgNPs was also observed on *Zea mays* (corn), *Citrullus lanatus* (watermelon) and *Cucurbita pepo* (zucchini) treated with different concentrations of AgNPs (0.05, 0.1, 0.5, 1, 1.5, 2 and 2.5 mg/ml). Increase growth rate and seed germination were observed for watermelon and zucchini depending on concentration of nanoparticles. 2 mg/ml AgNPs produced the highest seed germination rate (1.59 seeds/day) and percentage (73.33%) in watermelon while 0.5 and 2.5 mg/ml AgNPs triggered highest germination rate (1.68 and 1.66 seeds/day) and percentage (86.67 and 90%) in zucchini plants, respectively. However, in the corn, the toxic effect was noted in the sense of a reduction in root elongation as compared to control [44]. This study also showed the species dependent effect of AgNPs as positive in watermelon and zucchini and adverse in the corn. An improvement in the yield components of pea varieties was observed when AgNPs (0, 30, 60 and 90 ppm) were applied. The optimum concentration was 60 ppm [45].

Razzaq *et al.* [46] studied the effect of 0–150 ppm AgNPs on wheat and found that 25–50 ppm has the potential to significantly increase chlorophyll contents, plant height, fresh and dry weight over the control. Similar results were reported by Salama [35], where an increasing amount of AgNPs from 20 to 60 ppm resulted in an increase in the growth (length of root and shoot and leaf surface area) and biochemical attributes (chlorophyll, carbohydrate and protein contents) of *Phaseolus vulgaris* and *Zea mays*. Further increase in the level of AgNPs, 80–100 ppm decreased these parameters. This suggests that nanoparticles encourage growth at small dose but disappoint growth at large level of dosage [47]. It is further supported from the result of Seif *et al.* [48] that AgNPs from 20 to 60 ppm promote seed yield in treated borage plants opposed to control.

The impact of AgNPs is also species dependent. A study carried out by Pallavi Mehta and Srivastava [49] demonstrates the effect of AgNPs (0, 50 and 75 ppm) on *Triticum aestivum* (wheat), *Vigna sinensis* (cowpea) and *Brassica juncea* (*Brassica*). No effect was found on root and shoot parameters of wheat. However, optimum improvement in growth and root nodulation in cowpea was observed at 50 ppm and improved shoot parameters were found in *Brassica* at 75 ppm AgNPs. In *Zea mays*, a significant increase in growth of root and shoot was observed at 40 ppm AgNPs as compared to 20 and 60 ppm AgNPs [50]. An increase in root and shoot germination of mung bean, pigeon pea and chickpea was recorded when AgNPs treated seeds were germinated [51]. Similarly, the root length of *Eruca sativa* increased by 10 mg/l AgNPs [32]. In *Pisum sativum*, increase in seed protein and carbohydrate contents was found at 60 ppm AgNPs [52]. The effect of biosynthesised AgNPs studied on the growth and chemical

Table 2 Application of AgNPs to improve growth of plants

Plants (cultivars)	Ag nanoparticles (shape, size, conc.)	Findings	Reference
Glycine max	—	increase in total chlorophyll, chl-a, chl-b and root FW	[15]
Bacopa monnieri	—	significantly increased seed germination	[19]
Boswellia ovalifoliolata	spherical, 30–40 nm, 10, 20 and 30 mg/ml	promotion in seed germination and seedling growth with an increase in AgNPs concentration	[34]
phaseolus vulgaris L. and *Zea mays* L.	spherical, 10–30 nm, 20, 40, 60, 80 and 100 ppm	low concentration increased the growth (20–60 ppm) and higher concentration reduced it (80–100 ppm)	[35]
Brassica juncea	spherical, 0, 25, 50, 100, 200 and 400 ppm	increase in growth and antioxidant status (50 ppm AgNPs were optimum)	[36]
Radish, barley and *lettuce*	spherical, 10 nm, 1, 2.5, 5 and 10 mg/l	low concentration promote root length (1 mg/l) while higher concentration reduced it (10 mg/l)	[37]
Crocus sativus	0, 40, 80 or 120 ppm	40 and 120 ppm AgNPs increased root length and dry weight, respectively, in flooding stress	[38]
Arabidopsis	decahedral (45 ± 5 nm), triangular (47 ± 7 nm) and spherical (8 ± 2 nm)	decahedral AgNPs showed the highest degree of root growth promotion	[39]
Asparagus	—	chlorophyll, ascorbat and fibre were found higher in treated leaves	[40]
Trigonella foenum-graecum	Spherical, 8–21 nm, 1 µg/ml	significant enhancement in leaf number, root and shoot lengths and fresh weight	[41]
Vigna radiata	50 ppm	increase plant height, fresh and dry weight, length of root and shoot of *Vigna radiata*	[42]
Trigonella foenum-graecum	20 nm, 0, 10, 20, 30 and 40 µg/ml	low concentration of AgNPs promoted seed germination and early growth (10 µg/ml)	[43]
Zea mays, *Citrullus lanatus* and *Cucurbita pepo*	20 nm, 0.05, 0.1, 0.5, 1, 1.5, 2 and 2.5 mg/ml	positive effect was recorded in *Cucurbita pepo* and *Citrullus lanatus* and while negative in *Zea mays*	[44]
Pisum sativum	spherical, 10–100 nm, 0, 30, 60 and 90 ppm	improvement in yield components (optimum 60 ppm)	[45]
Triticum aestivum	10–20 nm, 0, 25, 50, 75, 100, 125 and 150 ppm	Increase in seedling growth (chlorophyll contents, plant height, fresh and dry weight) and yield. Optimum concentration was 25 ppm	[46]
Cucurbita pepo	0, 1.0, 10, 50, 100, 500 and1000 mg/l	stimulate growth at low dose but retard growth at high dosage	[47]
Triticum aestivum, *Vigna sinensis* and *Brassica juncea*	50 and 75 ppm	Optimum improves in in cowpea at 50 ppm and in brassica at 75 ppm. Wheat was found unaffected	[48]
Borage plant	20–60 ppm	increase seed yield	[49]
Zea mays	spherical	significantly increase root and shoot growth (optimum concentration 40 ppm)	[50]
Mungbean, Pigeon pea, Chick pea	spherical, 12–20 nm	increase in root and shoot lengths	[51]
Eruca sativa	—	increase root length	[32]
Pisum sativum	spherical, 54 nm, 0, 30, 60 and 90 ppm	significant increase in protein and carbohydrate contents	[52]
Triticum aestivum	9–35 nm	significantly increase shoot length, fresh and dry weight, chlorophyll, carbohydrate and protein contents	[53]
Phaseolus vulgaris L.	16.7 nm, 0.0, 5, 10, 20 and 60 ppm	significantly increased growth parameters and physiological response	[54]

attributes of *Triticum aestivum* and found that shoot length, fresh and dry weight, chlorophyll, carbohydrate and protein contents significantly increased at 20 and 40 ppm AgNPs [53]. A significant increase in growth characteristics and the physiological response was found in *Phaseolus vulgaris* under the application of AgNPs [54].

There are different suggestions and views exist about the mechanism of action of AgNPs to trigger the positive effect. It is thought that nanoparticles enter the seed coat and employ a useful effect on the seed germination processes. The possible reasons of increasing seed germination by nanoparticles, based on studies about the mechanism of effect of nanoparticles on seed germination, may include that they increase water absorption by seeds [5], increase the ability of seeds to absorb and utilise water and fertiliser, increase the level of nitrate reductase, promote the antioxidant system of seeds [15], drop H_2O_2, superoxide radicals and malonyldialdehyde content to decrease antioxidant stress, and promote the activities of some important enzymes including guaiacol peroxidase, superoxide dismutase catalase and ascorbate peroxidase [48]. These changes help in the improvement of seed germination in plants.

It is known that electron leakage during the cellular electron exchange produces ROS that cause a reduction in plant production. It is suggested that AgNPs improve the efficiency of electron transport pathway and prevent the formation of ROS leading to a higher yield of plants [36]. Another suggestion is that silver prevents the action of ethylene and improves the growth and yield of plants. As it is already established that ethylene reduces the plant height. It was found that mutants of tobacco and *Arabidopsis* have shown lesser height opposed to their wild because mutants produced ethylene in high concentration [56]. Due to small size, AgNPs have a large surface area in contact with plants and thus they attach to the cell surface to a great extent leading to their higher efficiency [57].

3 Conclusions

Nanotechnology has offered numerous inventive applications in different fields of science like medicines, energy, electronics and biology, which make this branch as a revolutionary science. AgNPs, because of their unique physical and chemical properties, are now intensively introducing in the field of agriculture for the betterment of human life. However, only a few number of studies were found to have a beneficial effect of AgNPs on the growth and development of crop plants. This compiled information evident that effect of AgNPs depends on the size, concentration and modes of application and varies from species to species. Yet, studies are unable to fix any convincing outcomes on the effective, lethal or optimum concentrations of AgNPs as a whole and species wise on which some controlling outlines can be made. This brief overview also suggests that sensible usage of AgNPs can promote the yield of our agricultural crops. However, further trials are needed to specify a particular concentration, suitable mode and time of application to appreciate the growth and yield enhancing ability of AgNPs for crops in eco-friendly manners.

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