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ROLE OF NANOPARTICLES IN GROWTH AND DEVELOPMENT OF PLANTS: A REVIEW

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ABSTRACT

Nanotechnology is the most novel field of 21st century. Nanotechnology has the ability to transform the agricultural and food industry with the help of various innovative tools for the molecular management of diseases, rapid disease detection, enhancing the ability of plants to absorb nutrients. Nanotechnology has the potential to increase yield of nutrient values and also plays a vital role in developing improved systems for monitoring ecological conditions and increasing the capacity of crops to absorb nutrients or pesticides. There are majority of nano-material which is known for its plant growth promoting effects. This paper reportedly contains the key role of nanoparticles in plants. This present review highlights the effects of nanoparticles on growth, flowering and seed production in plants. Recent researches on effects of nanoparticles on various plant crops have reported for an increased germination and growth of seed. The aim of this project is to study the roles of nanoparticles on various plants. Effects of these nanoparticles on plant growth and development can be easily highlighted in this review.

KEYWORDS: **Biomass, crops, germination, nanotechnology, seedling**

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INTRODUCTION

Nanotechnology serves as a precursor of new industrial revolution. Nanotechnology has the potential to bring alteration in the agricultural production. Nanoparticles (NPs) have unique physiochemical properties such as high reactivity, high surface area, particle morphology, tunable pore size. NPs also are called as "magic bullets", which contain nano-pesticide fertilizers, herbicides or genes, which aim to target particular cellular organelles in plant to pass their content. NPs have a plant growth promoting effects, which have vast applications in agriculture. Nanotechnological discoveries can release new applications in the world of agriculture. Nanotechnology has developed intensifying research such as productive scientific technology, renovation of food and agricultural wastes to energy, cleaning of water, chemical sensors, prevention of disease and treatment in plants with the help of nanocides.[1,2] Nanofertilizers or nano-encapsulated nutrients may have properties that are valuable to crops which releases the nutrients requirement, discharge of chemicals fertilizers in a controlled way that standardize plant growth and improve activity of target.[2,3] Nanoparticles have unique physicochemical properties to boost the plant metabolism.[4] Efficiency of NPs is resoluted by its surface covering reactivity, size, chemical composition and the amount at which they are effective.[5] Different nanoparticles have been used by researchers on the growth and development of plants. The activity of nanoparticles is dependent on their structures (Table 1).Effectiveness of NPs is dependent on its concentration which varies from plants to plants. NPs have been prepared by three methods which are as follows:

- Polymerization of monomers
- Ionic gelation or coacervation of hydrophilic polymers.
- Dispersion of preformed polymers

Nanotechnology appears to have an encouraging potential to make more supportable future of agriculture. Use of nanoparticles as fertilizer has a countless opportunity to increase crop yield and minimize environmental hazard. Nanotechnology shows potential in the field of interdisciplinary research. Application of nanotechnology include improvement of agricultural production using bio conjugated NPs (encapsulation), animal breeding , transfer of DNA in plants for the growth of insect pest resistant varieties, nanoformulations of agrochemicals for applying pesticides and fertilizers for crop improvement, nanosensors / nanobiosensors in crop protection for the identification of diseases and residues of agrochemicals, plant disease diagnostics, animal health, poultry production and postharvest management. The effect of NPs on plants varies from species to species and plant to plant (Figure 1).

EFFECTS OF NANOPARTICLES ON PLANTS (Table 2)

Aluminum oxide NPs

Root growth and development of tobacco (*Nicotiana tabacum*) seemed to be affected the most with a statistically significant decrease in root length as the concentration of NPs increased. The concentration of NPs increased the average root lengths of three week old tobacco seedlings significantly decreased. The concentrations of NPs increased the amount of leaves per seedling also significantly decreased. Aluminum oxide NPs have a negative effect on the growth and development of three week old tobacco seedling leaves. The average biomass of three week old tobacco seedlings decreased as the exposure to NPs increased. Al_2O_3NPs have a negative effect on the growth and development of tobacco seedlings.[6] Elongation was significantly improved in both treatments of 50 and 1000 mg/L nano-scale alumina on wheat (*Triticum aestivum*). Length of the roots was measured slightly lower than control in cases of 200 and 500 mg/L treatments while growth of the roots was apparently decreased and the uptake of aluminum by the roots was more than the uptake for other concentrations. The percentage of seed germination was approximately 90% for all treatments. Root lengths in the presence of 50 and 1000 mg/L NPs were significantly larger than in control while they were slightly decreased when compared to control in both 200 and 500 mg/L treatments. Nano-scale alumina did not have any significant inhibitory or increasing effects on shoot length and dry biomass.[7]

Carbon nanotubes

Carbon nanotubes (CNTs) were found to penetrate tomato seeds *(Solanum lycopersicum)* and affect their germination and growth rates. The germination was found to be dramatically higher for seeds that germinated on medium containing CNTs as compared to control (Table 2). CNTs can penetrate thick seed coat and support water uptake inside seeds. The activated process of water uptake could be responsible for the significantly faster germination rates and higher biomass production for the plants that were exposed to CNTs.[8]

Copper NPs

There was observable increase in germination percentage of wheat *(Triticum aestivum)* on soaking in nanoparticles suspension for two hours and much reduction was observed under the influence of copper NPs. Shoot growth was significantly increased on soaking in NPs suspension and incubation in distilled water in case of copper NPs. Severe reduction in seedling vigor occurred when seeds were soaked in copper NPs and incubated in distilled water.[9]

Copper oxide NPs

CuO NPs induce DNA damage in agricultural and grassland plants. Significant accumulation of oxidatively modified, mutagenic DNA lesions (7,8-dihydro-8-oxoguanine;2,6-diamino-4-hydroxy-5-formamidopyrimidine; 4,6-diamino-5-formamidopyrimidine) and strong plant growth inhibition were observed for radish (*Raphanus sativus*), under controlled laboratory conditions. Copper strongly inhibited radish seedling growth.[10] The seedlings of rape *(Brassica napus)* were grown in 1/2 strength Murashige and Skoog medium supplemented with CuO NPs at 0, 10, 100 and 1000 mgl^{-1} for 10 days. The results indicated that NPs induced the growth responses at 10 mgl^{-1} concentration. The decreases were observed in root and shoot elongation and root dry weights under higher concentrations (100 and 1000 mgl^{-1}) treatments. Exposure of canola germinated seeds to NPs caused changes in transcript levels of all four genes (*Auxin Responsive Protein, Protein Kinase, MPK3* and *MPK4*) in root and shoot tissues. At 10 mgl^{-1} concentration, CuO NPs supplementation promoted the growth response in *B. napus,* while higher concentrations resulted in toxic responses.[11] CuO NPs inhibited the plant growth of duckweed *(Lemna minor)* at lower concentration than bulk CuO. *L. minor* roots were easily broken in CuO NPs media under the experimental condition, and the inhibition occurred only partly because CuO NPs released Cu^{2+} in the culture media. Effects of CuO NPs, bulk CuO, and Cu^{2+} on the growth of *L. minor.* The CuO NPs showed the highest negative effect among the three kinds of material. When the CuO NPs concentration was 10 mgl^{-1}, the frond number changes of *L. minor* decreased significantly compared with that of the control. The second highest negative effect on frond number changes was caused by 2× concentration of Cu^{2+}, and the 2× Cu^{2+} released from 50 mgl^{-1} CuO NPs showed a significantly negative effect on the frond number changes of *L. minor*. Therefore, the negative effect of CuO NPs on frond number changes of *L. minor* was only partly due to the Cu^{2+} released by CuO NPs in the media. The effect of CuO NPs on the micro-growth of another kind of duckweed (*Landoltia punctata*) and the uptake of Cu into plant tissue in comparison with a reference toxicant, $CuCl_2$, have been studied.[12] All of the three copper treatments showed negative effects on the fresh weight of *L. minor.* The negative effect of CuO NPs on fresh weight was the greatest among the three treatments, followed by 2× Cu^{2+} concentration released from CuO NPs. The plant was consisted in two parts, namely, the frond and root. The fresh weight of this plant consisted mainly of the frond, because the root of this kind of plant is very tender and light. The micro-growth of *L. minor* indicated that CuO NPs exhibited greater effect on the growth of *L. minor* than the bulk CuO in the same concentration.[13] CuO NPs exhibited prominent inhibition on lettuce *(Lactuca sativa)* germination even at trace levels as compared with that of Cu ions, reflecting that CuO solids (bulk or NPs) are intrinsically more toxic than Cu^{2+} ions. Therefore, CuO NPs are not a good candidate as a Cu micronutrient fertilizer. But, CuO NPs may need to be specifically regulated regarding the release of Cu contaminants into the soil or water environment.[14]

Iron NPs

Iron nanoparticles showed increase in germination percentage of wheat *(Triticum aestivum)* on soaking in NPs and incubation in distilled water. In case of iron NPs there was increase in germination percentage on soaking and incubation in NPs suspension were not affected by the NPs. Iron NPs exhibited severe reduction in root growth when seeds were soaked in NPs and incubated in distilled water while root growth enhanced on soaking in distilled water and incubation in NPs suspension. Iron NPs resulted in significant increase in shoot growth on soaking in NPs and incubated in distilled water. Even significant increase occurred with iron treatment as compared to control. Severe reduction in seedling vigor on soaking in iron NPs and incubated in distilledwater.[9]

Iron oxide NPs

The effects of positive (PC) and negative (NC) charged iron oxide (Fe_2O_3) NPs (IONPs) on the physiology of *Arabidopsis thaliana* at concentrations of 3 and 25 mg/L. The 3 mg/L treated plants did not show evident effects on seeding and root length. However, the 25 mg/L treatment resulted in reduced seedling (positive-20% and negative-3.6%) and root (positive-48% and negative-negligible) length. Interestingly, treatment with polyethylenimine (PEI; IONP-PC coating) also resulted in reduced root length (39%) but no change was observed with polyacrylic acid (PAA; IONP-NC coating) treatment alone. Interestingly, the treated plants did not show any observable phenotypic changes in overall size or general plant structure, indicating that environmental nanoparticle contamination could go dangerously unnoticed. ONP-PC and IONP-NC have inhibitory effects on development in *A. thaliana*. Charged IONP are transported throughout the plant and can be detected in root, leaf, floral and silique tissue. IONP-PC had significant effects on seedling and root length in *A. thaliana* but most of the effect on root length could be attributed to the PEI coating on the nanoparticle.[15] Iron oxide NPs significantly enhanced root elongation of lettuce *(Lactuca sativa)* seedlings by 12–26 %, indicating that Fe NPs could be used as a Fe fertilizer as well at low application rates (5–20 ppm).[16]

Iron pyrite (FeS_2) NPs

The plants developed from iron pyrite nanoparticle treated seeds of spinach *(Spinacia oleracea)* exhibited significantly broader leaf morphology, larger leaf numbers, increased biomass. Along with higher concentration of calcium, manganese and zinc in the leaves when compared to the plants developed from control seeds. We further investigated the possible mechanism resulting in the biomass enhancement following seed treatment. There is an enhanced breakdown of stored starch in the iron pyrite treated seeds resulting in significantly better growth.[16]

Magnetic NPs (Fe_2O_3 , Fe_3O_4)

Application of both NPs and MNPs showed an effect on cell viability and cell growth. However, there were significant differences in effects shown by NPs and MNPs. Non-modified MPs had no significant effect on BY-2 cell viability (96% after 120-h treatment under the highest concentration of 100 ng/mL compared to control—99%), application of both -OH and -NH_2 modified NPs led to a significant reduction of cell viability at all concentrations. At the lowest concentration (1 ng/mL), viability of BY-2 cells was reduced to 62.5% (Fe_2O_3-NH_2) and 75% (Fe_2O_3-OH) after 120h treatment. Treatment of BY-2 cells with high concentration of MNPs (100 ng/mL) resulted in a reduction of viability to 45% for Fe_2O_3-NH_2 and to 60% for Fe_2O_3-OH. Application of NPs and Fe_2O_3-NH_2 caused lesser enhancement in fresh weight at the lowest concentration (1 ng/mL). In comparison to control untreated BY-2 cells (for 7% to 107% in the case of NPS and almost for 4%

to 104% for Fe_2O_3-NH_2). All other experimental variants demonstrated growth depreciation as compared to control. The most evident growth depreciation was observed in the case of Fe_2O_3-NH_2 at the highest concentration (100 ng/mL), where fresh weight was reduced to 85% in comparison to untreated BY-2 cells.[17]

Manganese oxideNPs

Manganese oxide NPs significantly enhanced root elongation of lettuce *(Lactuca sativa)*seedlings by more than 50 %, showing that Mn NPs could be used as a Mn micronutrient fertilizer or plant growth enhancer, thereby improving agronomic productions. Moreover, the NPs had no or little phytotoxicity at concentrations of <50 ppm.[14]

Silicon dioxide NPs

Various effects of silicon dioxide have been observed in plant growth, yield, and biotic and abiotic resistance.[18,19,20,21,22] It acts as a physical mechanical barrier, and is placed on the walls of epidermis and vascular tissues of the stem, leaf sheath of most plants especially monocots.[18,23,24] It also controls the physiological activities in plants.[25] Nano-SiO_2 gives better seed germination by providing that better nutrients availability to maize seeds.[26,27] Nano-SiO_2 improved seedling growth and quality, including mean height, root collar diameter, main root length, and the numberof lateral roots of seedlings and also induced the synthesis of chlorophyll.[25] Under abiotic stress, nano-SiO_2 increase seed germination. Under salinity stress, nano-SiO_2 improves leaf fresh and dry weight, chlorophyll content and proline accumulation. The lower concentration of nano-SiO_2 enhances seed germination of tomato *(Lycopersicum esculentum).*[28]The concentration of 8 $gL^{-1}$of $nSiO_2$ improved percent seed germination by 22.16%, germination mean time by 3.98%, seedling vigor index by 507.82% and seed germination index by 22.15% with respect to controls. Concentration of 8 gL^{-1} of $nSiO_2$ enhances seedling fresh weight by 116.58% and seedling dry weight by 117.46% with respect to control[28] and also $nSiO_2$ plays a very important role in root and shoot growth.[28] 1 mM silicon dioxide nanoparticles ($nSiO_2$) could considerably alleviate the adverse effect of salt stress on germination percentage, root and shoot length, seedling weight, mean germination time, seedling vigor index and cotyledon reserve mobilization of lentil (*Lens culinaris*). The suppressive impact with higher $nSiO_2$ concentration (2 Mm) shows the need for cautious application of these particles during seed germination of lentil. Salinity significantly delayed germination and higher salt concentrations reduced the percentage of germinated seeds and seedling growth parameters. This approach involves application of favorable nanoparticles to improve germination, early seedling growth, and final crop yield under salt stress.[29] Mixture of nanoscale SiO_2 (nano-SiO_2) and TiO_2 (nano-TiO_2) could increase nitrate reductase in soybean (*Glycine max*), enhance its abilities of absorbing and utilizing water and fertilizer, stimulate its antioxidant system, and apparently hasten its germination and growth.[30,31] The significant reduction in growth and development indices due to the salinity stress. Leaf, dry and fresh weight of basil (*Ocimum basilicum*) reduced by increment in NaCl concentration while significantly increased with silicon nanoparticles application. The chlorophyll content reduced in salinity stress, but increased by silicon NPs treatment.[32]

Silver NPs

Based on the analysis of AgNPs accumulation in plant tissues of rice seed (*Oryza sativa*), it implied that the higher uptake was found when the seeds were treated with the smaller AgNPs, 20nm diameter AgNPs, but it was trapped in the roots rather than transported to the leaves. These resulted in the less negative effects on seedling growth, when compared to the seed soaking with the larger AgNPs with 150nm diameter. The negative effects of AgNPs were supported by leaf cell deformation when rice seeds were treated with 150nm diameter AgNP at the concentration of 10 or 100mg/L during seed germination. This study demonstrated that exposure of rice seeds to AgNPs had a clear phytotoxic effect on the rice seedlings. The effect of AgNPs on rice was dependent upon the size and concentration of the AgNPs. Increasing the AgNP concentration over the range of 0.1 to 1000mg/L increased the inhibition level of seed germination and subsequent seedling growth, especially at the higher level of 100 and 1000mg/L, for each size of AgNPs. Likewise, increasing the size of the AgNPs over the 20–150nm diameter range increased the inhibition effect upon seed germination and seedling growth. The inhibition effects were due to both the penetration and transport of AgNPs through plant tissues.[33] The test plants *Vigna radiata* exhibited increase in biomass but at variable rate which depends on plant species, concentration of Ag nanoparticle and ions and its exposure time. Significant reduction on root fresh weight was observed at 500 µg/mL in *V.radiata*compared to control after 6th day. *V. radiata* reported significant inhibition on shoot fresh weight at 1000 µg/mL of Ag nanoparticle solution after 3rd day. *V. radiata* showed significant retardation on dry weight of root at 1000 µg/mL of Ag+ ions solution after 12th day. The decrease on shoot dry weight with increase in NPs and ion concentration was also observed after 12th day.[34] There was a significant reduction on root fresh weight at 500 µg/mL and 1000 µg/mL of Ag NPs solution in *Bactris campestris* plants. *B. campestris* showed significant retardation on shoot fresh weight at both 500 µg/mL and 1000 µg/mL of Ag NP solution compared to control.[34] There was a reduction in germination percentage of wheat (*Triticum aestivum*) on exposure to silver and copper NPs. When seeds were soaked in silver NPs and then placed in distilled water for germination there was significant increase in germination percentage as compared to seeds when soaked in water or NPs and placed in NPs suspension for germination. Silver NPs resulted in reduction in root growth when seeds were soaked in distilled water and incubated in NPs while root growth enhanced on soaking in NPs and incubated in distilled water. Shoot growth increased on soaking in silver NPs suspension and incubated in distilled water. Seedling vigor increases on silver treatment as soaking in NPs and incubated in distilled water.[9] It was observed that the growth of mung bean *(Phaseolus radiatus)* was adversely effected by increasing the AgNPs exposure concentrations. As compared to the control growth, the percent seedling growth of the *P. radiatus* exposed to AgNPs of 40 mg L^{-1} was 20% increased.[35]*P. radiatus*, was subjected to silver NPs resulted in reduced root growth, root length and biomass were observed.[35,36] The growth of durra *(Sorghum bicolor)* was adversely effected by increasing the AgNPs exposure concentrations. As compared to the control growth, the percent seedling growth of the *S. bicolor* exposed to AgNPs of 40 mgl^{-1} was 47% increased. *P. radiates* was more sensitive than *S. bicolor* to AgNPs. The growth of *S. bicolor* was also measured by shoot and root length, and root growth was determined to be a more sensitive endpoint than shoot growth.[35] *S. bicolor* was subjected to silver NPs resulted in reduced root growth, root length and biomass were observed.[35,36] AgNPs inhibited seedling growth of ryegrass *(Lolium multiflorum)*. While exposed to 40 mgl^{-1} GA-coated AgNPs, seedlings failed to develop root hairs, had highly vacuolated and collapsed cortical cells and broken epidermis and root cap. AgNP toxicity led to significant reductions in root growth rate and changes in cell structure and root morphology. Both the 6 nm AgNPs and ionic silver significantly reduced growth, resulting in shorter shoots and roots and lower biomass. The growth inhibition from 6 nm AgNPs was significantly stronger than that from $AgNO_3$ at the same total Ag concentration. Cysteine alleviated AgNO3 toxicity for seedling growth but did not significantly alter AgNP toxicity.[36] Small concentrations of silver NPs had a stimulating effect on the growth of the corn *(Zea mays)* plantlets, while the enhanced concentrations induced an inhibitory effect. However, increasing concentration of silver NPs from 20 to 60 ppm has led to an increase in shoot and root lengths, leaf surface area, and chlorophyll contents of the Corn plant. With increase in Ag NPs concentration, the shoot and root lengths of corn also increase. Concentration of 80 and 100 ppm of silver NPs showed statistically significant inhibition on shoot and root elongation. For Ag NPs at 60 ppm treatment, fresh weight increased 35 % and dry weight 33 % over control was observed. At the highest concentration of 100 ppm, 14 % decrease in fresh weight and 20 % decrease in dry weight was observed. The leaf surface area of the corn was significantly increased as the silver NPs increased till certain level (60 ppm), the leaf surface area was found to be decline. For corn the high leaf surface area was observed at concentration of 60 ppm (26 %) over control. At highest concentration 100 ppm the decline in leaf surface area was observed in the corn plant (23 %). In concentration 60 ppm of silver NPs chlorophyll A and B increases by 46% and 26% compared to control in corn. Above 60 ppm concentration of AgNPs, the chlorophyll contents of the tested corn plants decreased significantly.[37]

Silver nitrate ($AgNO_3$) and gum arabic silver (GA-Ag)NPs

Silver nanoparticles (AgNPs) are one of the most widely used engineered nanoparticles (ENPs) and are expected to enter natural ecosystems. In the direct exposure experiments, PVP-AgNP had no effect on germination while 40 mg Ag L21 GAAgNP exposure significantly reduced the germination rate of ryegrass *(Lolium multiflorum)* and enhanced the germination rate of one species. In general root growth was much more affected by Ag exposure than was leaf growth. The magnitude of inhibition was always greater for GA-AgNPs than for $AgNO_3$ and PVP-AgNPs. The plant growth response differed by taxa with *Lolium multiflorum* growing more rapidly under both $AgNO_3$ and GA-AgNP exposures and all other taxa having significantly reduced growth under GA-AgNP exposure. $AgNO_3$ did not reduce the growth of any species while PVP-AgNPs significantly inhibited the growth of only one species. Exposure to GA-AgNPs affected seedling growth for all tested plant species while exposure to PVP-AgNPs and $AgNO_3$ affected seedling growth for only one species, *L. multiflorum*. The grass *L. multiflorum* responded positively to both the GA-AgNP and $AgNO_3$ treatments, and its aboveground biomass increased by 55% and 45%, respectively, as compared to control plants.[38] The significant effect of Ag on germination in the soil exposure experiment was inhibition of germination of *Phytolacca americana* by GA-AgNPs. The magnitude of plant biomass change was greater for GA-AgNPs than for PVP-AgNPs or $AgNO_3$. Exposure to GA-AgNPs affected seedling growth for all tested plant species while exposure to PVP-AgNPs and $AgNO_3$ affected seedling growth for *Phytolacca americana*. Both *Carex* spp. and *E. fistulosum* had significantly reduced aboveground growth when exposed to GAAgNPs. *Phytolacca americana* above ground growth was reduced 62% and 65% when exposed to PVP-AgNPs and GA-AgNPs, respectively.[38]

Titanium dioxide NPs

Titanium dioxide is the common compound of titanium which acts as a popular photo-catalyst, and is used in the production of pigments.[39] In plants, titanium plays a fine role to stimulate production of more carbohydrates and helps in encouraging growth and rate of photosynthesis.[40,41,42] TiO_2 NPs gives better seed germination and enhances radicle and plumule growth of canola seedlings.[43] TiO_2 NPs that increases plant growth of wheat and gives up components under water deficit stress condition.[44] TiO_2 NPs control enzymes activity that are implicated in metabolism of nitrogen such as glutamate dehydrogenase, nitrate reductase, glutamine synthase and glutamic-pyruvic transaminase that helps out the plants to absorb nitrate and also aids in the conversion of inorganic nitrogen to organic nitrogen in the form of protein and chlorophyll, that might raise the fresh weight and dry weight of plant.[45,46] TiO_2 NPs help in promoting aged seeds' vigor and formation of chlorophyll and encourage Ribulose 1, 5-bisphosphate carboxylase (Rubisco) activity and enhances photosynthesis rate which results in increasing plant growth and development.[45] TiO_2NPs increases light absorbance which further helps in protecting chloroplasts from aging, and extend the photosynthetic time of the chloroplasts.[45] The TiO_2 NPs were foliar sprayed at concentration of 10 mgl^{-1} on the leaves of 14 days old mung bean plants. Higher plant growth was observed in those plants which were treated by TiO_2 NPs. With respect to control, a major improvement was observed in shoot length (17.02%), root length (49.6%), root area (43%), root nodule (67.5%), chlorophyll content (46.4%) and total soluble leaf protein (94%).[47] Nano-TiO_2 has no effect on root length of rice seed *(Oryza sativa)*. Rice seed germination occurred normally but the toxic effect is more pronounced in the roots, probably due to the rice seed coat, which can act as a protector for the embryo but cannot totally guard the whole seed.[48] This result related is similar to the report of Yang and Watts[49] who found that alumina NPs (nano-Al_2O_3) at 2000 mg/L could inhibit root elongation of five plant species.[48]

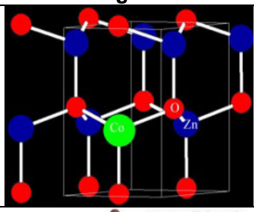
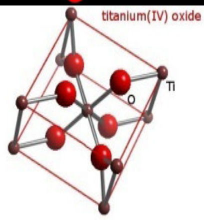
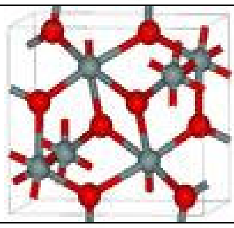
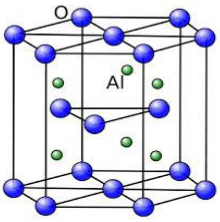
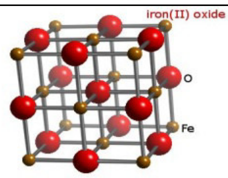
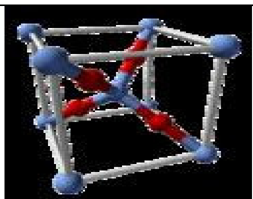
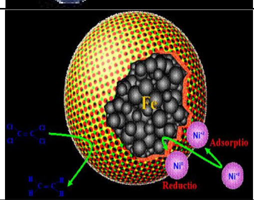
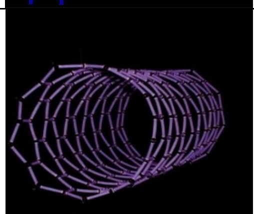
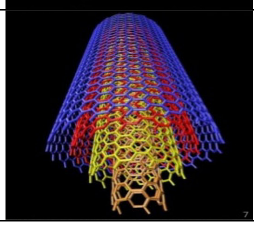
Zero-valent iron NPs

The exposure of peanut seeds *(Arachis hypogaea)* to nanoscale zero valent iron (NZVI) at all the tested concentrations altered the seed germination activity, especially the development of seedlings. In comparison with the deionized water treated controls (CK), all of the NZVI treatments had significantly larger average lengths. Further investigations with transmission electron microscopy (TEM) and thermo gravimetric analysis (TGA) suggested that NZVI particles may penetrate the peanut seed coats to increase the water uptake to stimulate seed germination. The growth experiments showed that although NZVI at a relatively high concentration (320μmol/L) showed phytotoxicity to the peanut plants, the lower concentrations of NZVI particles stimulated the growth and root development of the plants. Because low concentrations of NZVI particles stimulated both the seedling development and growth of peanut, they might be used to benefit the growth of peanuts in large scale agricultural settings. Low concentrations of NZVI stimulated not only seed germination but also the growth of peanut plants. Because iron deficiency occurs in a variety of soils, it causes serious problems to various types crops including peanuts.[50,51] Low concentrations of iron nutrients, such as EDTAFe, thus are often used as a fertilizer to enhance the yield.[52,53,54]

Zinc and zinc oxide NPs

The crop yield and quality of product can be affected by deficiency of Zn. Researchers have demonstrated essentiality and role of zinc in plant growth, reproduction and yield.[55,56,57,58,59,60]The effect of nanoscale zinc oxide was studied on germination and observed with more growth and yield.[61] Zinc oxide NPs have major physical, optical and antimicrobial properties and so have remarkable potential to improve cultivation. In many studies, it was suggested that Zinc Oxide nanoparticles (ZnO NPs) enhance plant growth and their development. Lower concentration of ZnO NPs exhibited significant effect on seed germination.[61,62,63,64] Higher dose of ZnO NPs impaired seed germination. The effect of NPs on germination depends on concentrations of NPs. ZnO NPs induced a significant improvement in *Cyamopsis tetragonoloba* plant biomass, shoot and root growth, root area, chlorophyll and protein synthesis.[59] Roots of *Vigna radiata*and *Cicer arietinum* absorbed ZnO NPs and promoted the root and shoot length, root and shoot biomass.[65] Nano ZnO supplemented with MS media promoted somatic embryogenesis, shooting, regeneration of plantlets, and also induced proline synthesis. ZnO NPs increased starch content in cucumber *(Cucumis sativus).* It was observed that the growth inhibition was higher in biologically synthesized ZnO than chemical ZnO NPs as well as other common antimicrobials. Seedling growth and seed germination in onion was increased in lower concentrations of ZnO NPs but decreases at higher concentrations.[64] The plants treated with ZnO NPs at the concentration of 20 and 30 $\mu g ml^{-1}$ determine better growth and flowered 12-14 days earlier than the control.[66] Shoot and root elongation, the fresh and dry weight of sesame (*Sesam umindicum L*) seedlings were influenced by the application of various doses of ZnO NPs. ZnO slightly increased dry and fresh weight at a lower concentration while an excess of ZnO NPs reduced the biomass.[67] The percent germination of cucumber *(Cucumis sativus)* showed a significant increase in ZnO levels of 400 and 1600 mgl^{-1}, as compared to controls, germination was determined after 12 days of exposure. The effect of ZnO NPs and Zn^{2+} ions on root seedling growth of cucumber was positive as hormesis was observed.[68]Seedlings germinated in 200, 400, and 800 mgl^{-1} of ZnO NPs were 2.7, 1.9, and 1.4 times larger than control roots, respectively. Cucumber biomass yield displayed a U-shaped response, since concentrations between 100 and 400 mgl^{-1} of ZnO NPs decreased biomass by about 10 %.[69,30] Nano-ZnO is found to stunt roots length and reduce number of roots of rice Seed *(Oryza sativa L).*[48] 200 and 300 mg/L ZnO NPs treatments reduced *Arabidopsis* growth by ~20 and 80%, respectively, in comparison to the control. Pigments measurement showed that Chlorophyll a and b contents were reduced more than 50%, whereas carotenoid contents remain largely unaffected in 300 mg/L ZnO NPs treated *Arabidopsis* plants. Consistent with this, net rate of photosynthesis, leaf stomatal conductance, intercellular CO concentration and transpiration rate were all reduced more than 50% in 300 mg/L ZnO NPs treated plants. Results showed that the inhibition of chlorophylls biosynthesis, leading to reduce in photosynthesis efficiency in the plants.[70] The presence of ZnO NPs in the culture media significantly inhibited germination of black mustard *(Brassica nigra)* seeds. Increase of NPs concentration decreased germination efficiency recorded on 5th day of seed inoculation. ZnO NPs in the culture media generated stimulatory effect on shoot growth but inhibited root length. At 500mg/L ZnO, 64% increase in shoot length was observed compared to control, while at the same concentration 61% reduction in root length was observed. Although, there was positive effect on shoot lengths but shoot fresh weight decreased by increasing the NPs in the media, due to reduction in diameter of stem. At 1500 mg/L NPs, 21% reduction in shoot fresh weight was observed. Comparatively root fresh weight significantly decreased; 73% at 500mg/L and 87% at 1500mg/L. The shoot dry weight did not show any significant change at 500 and 1000mg/L but at 1500mg/L boost was observed.[71] The inhibitory effects of treatments on the growth of rape *(Brassica napus)* were in the order Zn^{2+}>> ZnO BPs > ZnO NPs. Overall, in the present study, the toxicity of ZnO NPs on *B. napus* was lower than those of Zn^{2+} or ZnO BPs.[72]

Table 1
Structures of nanoparticles.

S. No.	Figure	NPs	Reference
1		Zinc oxide	73
2		Titanium dioxide	74
3		Silicon dioxide	75
4		Aluminum oxide	76
5		Iron oxide	77
6		Silver oxide	78
7		Zero valent iron	79
8		Single-bond carbon nanotubes	80
9		Multi-bond carbon nanotubes	80

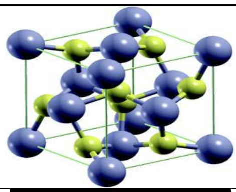
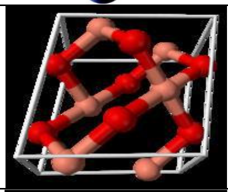
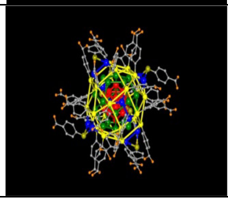
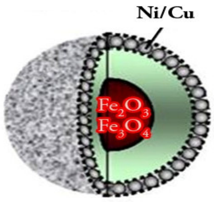
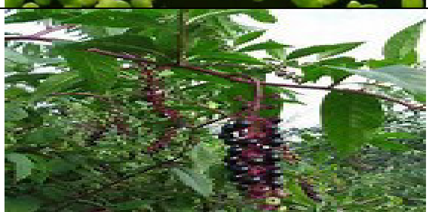
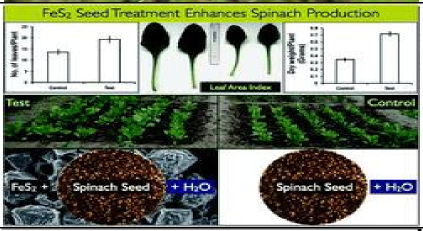
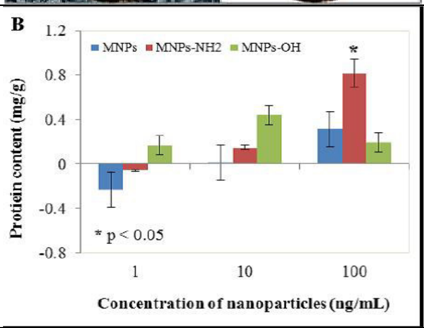
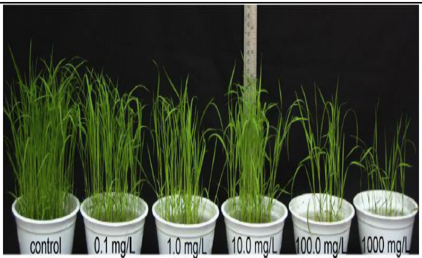
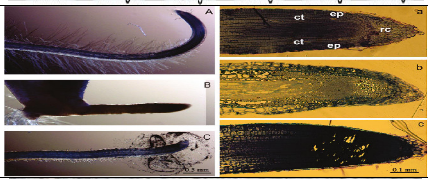
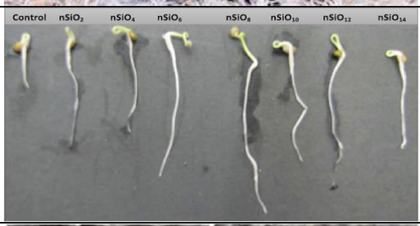
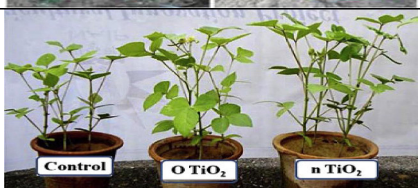
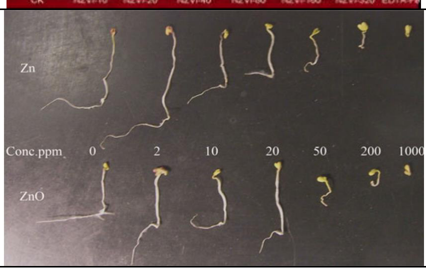
10		Iron pyrite (FeS_2)	81
11		Copper oxide	82
12		Silver	83
13		Magnetic nanoparticle(Fe_2O_3, Fe_3O_4)	84

Table 2
Effects of various nanoparticles on the growth and development of plants.

S. No.	Figure	NPs and Plants	End points	Reference/s
1		$AgNO_3$ and GA-Ag on ryegrass *(Lolium multiflorum)*	Rapid plant growth.	56
2		Aluminum oxide on wheat (*Triticum aestivum*)	Significantly improved elongation.	51
3		Aluminum oxide on tobacco (*Nicotiana tabacum*)	Negative effect on the growth and development of tobacco seedlings.	44
4		Carbon nanotubes on tomato seeds *(Solanum lycopersicum)*	Enhance germination and growth rates.	67

5		Copper on wheat (*Triticum aestivum*)	Significant increase in germination percentage on soaking in nanoparticles suspension and severe reduction on soaking and incubation in copper nanoparticles.	52
6		Copper on radish *(Raphanus sativus)*	Severe reduction in root growth when seeds were soaked and incubated in copper NPs.	68
7		Copper on rapeseed *(Brassica napus)*	At low concentration, promoted the growth response, while higher concentrations resulted in toxic response.	79
8		Cu, Zn, Mn, and Fe oxide on lettuce *(Lactuca sativa)*	CuO inhibited the seed germination. ZnO caused no enhancement of the seed germination. MnOx significantly enhanced root elongation. FeOx significantly enhanced root elongation.	77
9		CuO on duckweed (*Lemna minor)*	Inhibited the plant growth at lower concentration.	55
10		GA-Ag on pokeweed **(***Phytolacca americana)*	Inhibit germination.	56
11		Iron on wheat (*Triticum aestivum*)	Severe reduction in root growth when seeds were soaked in NPs and incubated in distilled water while root growth enhanced on soaking in distilled water and incubation in NPs.	52

12		Iron oxide on *Arabidopsis thaliana*	Inhibitory effects on development.	49
13		Iron pyrite (FeS_2) on spinach *(Spinacia oleracea)*	Significantly better growth.	70
14		Magnetic NPs on tobacco BY-2 cell suspension culture *(Nicotiana tabacum Linn.)*	Viability of BY-2 cells was reduced. Lower enhancement of fresh weight in the lowest concentration (1 ng/mL) in comparison with control untreated BY-2 cells.	65
15		Silica on basil (*Ocimum basilicum)*	Increase leaf, dry and fresh weight.	47
16		Silicon dioxide on lentil (*Lens culinaris)*	Favorable effect on lentil seed germination under salinity stress.	48
17		Silver on corn *(Zea mays)*	Shoot and root lengths increased at low conc. (60 ppm) But decreased at high conc. (60 ppm).	78
18		Silver on durra (*Sorghum bicolor)*	Reduced root growth, root length and biomass.	58,59
19		Silver on mung *(Vigna radiata L.)*	Decrease on shoot fresh weight, decrease on shoot dry weight, increase biomass.	46
20		Silver on mung bean (*Phaselous radiatus)*	Reduced root growth, root length and biomass.	58,59

21		Silver on rice seed *(Oryza sativa)*	Increasing the AgNP concentration over the range of 0.1 to 1000mg/L increased the inhibition level of seed germination and subsequent seedling growth.	80
22		Silver on ryegrass (*Lolium multiflorum)*	Reduced root growth, root length and biomass.	58
23		Silver on spiny palm (*Bactris campestris)*	Reduction on shoot fresh weight, reduction on root fresh weight.	46
24		Silver on wheat (*Triticum aestivum*)	Reduction in root growth when seeds were soaked in distilled water and incubated in NPs while root growth enhanced on soaking in NPs and incubated in distilled water.	52
25		SiO_2 on tomato *(Lycopersicum esculentum)*	The lower conc. of nano-SiO_2 enhances seed germination of tomato.	43
26		SiO_2 and TiO_2 on soya bean *(Glycine max)*	Promotor effect on germination.	60,61
27		Titanium dioxide on mung *(Vigna radiata L.)*	Enhanced plant growth.	42
28		Zero-valent iron on peanut seedling *(Arachishypogaea)*	Stimulated both the seedling development and growth.	69
29		Zinc and zinc oxide on rape seeds *(Brassica napus)*	Inhibited root growth.	60,66

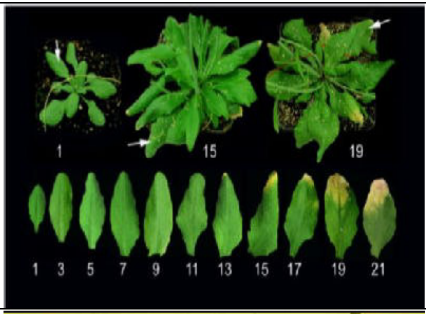
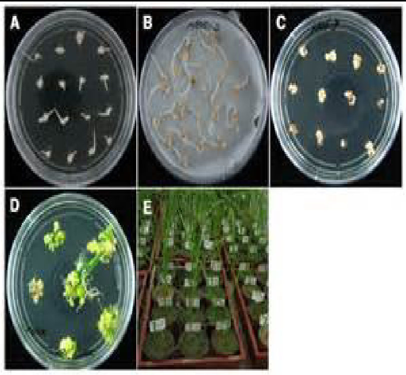
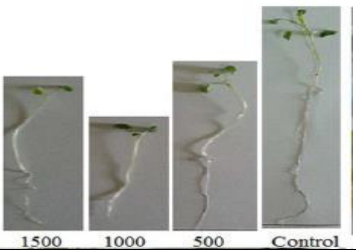
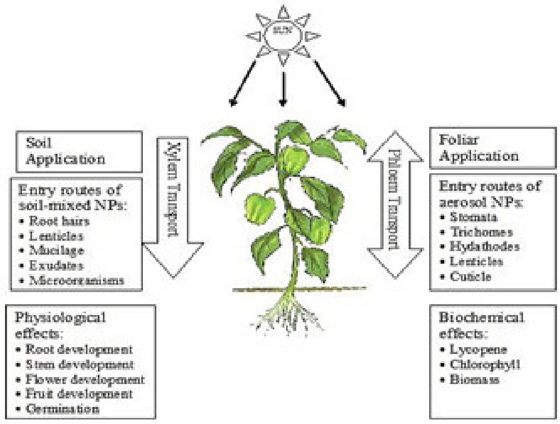
30		Zinc oxide on *Arabidopsis* plants	Inhibition of chlorophyll biosynthesis, leading to the reduction in photosynthesis efficiency.	64
31		Zinc Oxide on onion *(Allium cepa L.)*	Seed germination increased in lower conc. of ZnO NPs but decreases at higher conc.	18,41
32		Zinc oxide on sesame **(***Sesamum indicum L.)*	Slightly increased dry and fresh weight at a lower conc. while an excess of ZnO NPs reduced the biomass.	50
33		ZnO and TiO_2 on rice seed (*Oryza sativa L*)	No reduction in the percent seed germination, Nano-ZnO is found to stunt roots length and reduce number of roots. Whereas nano-TiO_2 has no effect on root length.	62,54
34		ZnO on black mustard seedlings and stem *(Brassica nigra)*	Significantly inhibited germination, stimulatory effect on shoot growth but inhibited root length.	71
35		ZnO on cucumber *(Cucumis sativus)*	Significant increase in percent germination. Decreased root seedling growth. Decreased biomass.	75,60

Figure 1
Application of nanoparticles and their physiological and biochemical effects.



CONCLUSION

Nanotechnology is an emerging technology working in all fields of science. Extensive research is going on for commercializing nano products throughout the world. The function of nanoparticles in agriculture aims to reduce applications of plant protection products, minimize nutrient losses and increase yields. Zinc oxide nanoparticles serve as one of the most flexible materials, due to their miscellaneous properties, functionalities, and applications. ZnO NPs have tremendous physical, optical and antimicrobial properties. As far as their usage is concerned nanoparticles play a significant role in agriculture, where colloidal solution of ZnO NPs is used in nanofertilizers. Metal nanoparticles when applied as foliar spray, enhances crop production. Lower concentration of ZnO NPs has higher seed germination. The effect of NPs on germination depends on concentrations of NPs. As the food demand is increasing everyday and the yield of staple food crops is much low, so it is required to commercialize metal nanoparticles for sustainable agriculture. TiO_2 NPs act as a plant nutrient fertilizer to enhance crop production by stimulating metabolic activities of plants. The current study shows that the concentration of $nSiO_2$ broadly increases seed germination rate. The function of $nSiO_2$ is to give better percentage of seed germination, mean germination time, seed germination index, seed vigour index, seedling fresh weight and dry weight. The previous experiment shows that $nSiO_2$ is used as a fertilizer for the crop improvement. So it is very obvious that $nSiO_2$ has an important impact on the seed germination rate. The point that has been given importance is the size of nanoparticles which plays an important role in the behavior, in the reactivity and in the toxicity of NPs. A food demand is increasing every day and the yield of staple food crops is much low. However today it is important to enhance the productivity of crops to feed the growing world population. So it is required to commercialize metal nanoparticles for sustainable agriculture.

CONFLICT OF INTEREST

Conflict of interest declared none.

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