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Effects of Nanoparticles on Seed Germination, Growth, Phytotoxicity and Crop Improvement

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ABSTRACT

The interactions between nanoparticles (NPs) and plant cells are one of the most important aspects that are involved in the development of plant nanotechnology. The NPs released in plant cells inevitably interact with the basic organelles of plant cells. Because thousands of studies have addressed plant transformation, conversion, regeneration, accumulation and phytotoxicity of different types of NPs and even their transmission across the food chain, most of the important issues in the field of nanotechnology in plant interactions have remained for a long time. In this review, uptake and translocation pathways of NPs in plants, phytotoxicity, interactions, improvement and transformation are systematically reviewed. In particular, analytical nanotechnology and methodology and future approaches to related fields are proposed.

Key words: Growth, Nanoparticles, Phytotoxicity, Seed.

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Nanotechnology is a fast-developing research field and has significant effects on society, economy and the environment with implications for plant diversity and our health, medicine, biometric and treatment of liquid, solid and gaseous residues. Recent advances in nanotechnology have affected many industries including life science, manufacturing, electronics, biomedical applications, agriculture and renewable energy (Fulekar, 2010; Ma *et al.* 2015). In-depth studies are needed to establish the effect of nanomaterials on plant growth and agroecosystems and to develop smart nanotechnology applications for crop improvement (Sanzari *et al.* 2019). Nanotechnology has generated various types of nanoparticles (NPs) with differences in size, shape, surface charge and surface chemistry (Albanese *et al.* 2012). Nanoparticles (NPs) are broadly defined as the small particles with at least one dimension size between 1 and 100 nm in diameter (Auffan *et al.* 2009). Through industrial waste, many types of nanomaterials are synthesized and have an impact on the environment in which metallic NPs are found in greater quantities. Metal-based NPs have been extensively used in various applications (Zhu and Nguguna 2014). Due to their unique properties and novel characteristics, NPs have been widely used in many aspects of daily life and energy production, including cosmetics, catalysts, semiconductors, drug carriers and environmental energy, *etc* (Nel *et al*. 2006). The number of studies and researchers focusing on the positive and negative effects of this field has increased from year to year and positive effects have also been found (Hullmann 2007). Nanomaterials represent physical and chemical characteristics that can modify their natural properties, such as reactivity, conductivity and optical sensitivity so that these materials produce negative or positive effects in living cells in plants and animals (Vecchio *et al.* 2012, Shang *et al*. 2014). The presence of NPs in water, air and soil which show unavoidable effects on plants and is directly or indirectly absorbed by the root or root surface by any physical or chemical process and NPs are transported through the stem to leaves and other parts of plants and can accumulate in fruits and seeds (Maiti *et al.* 2015). Pulses play an important role in Indian agriculture they restore soil fertility by fixing atmospheric nitrogen through their nodules. They are drought resistant and prevent soil erosion due to their deep root system and good ground coverage (Kavitha *et al*. 2019). The increase in nutrients can be attributed to the higher yield coupled with a slight improvement in ridgrams nutrients at higher nutritional supplements concentration in seed and non-seed parts (Nagamani *et al.* 2020). Plants serve as a potential pathway for the transportation of different types of NPs (Rico *et al.* 2011). Agriculture is an area that has been modified with the inclusion of a variety of nanomaterials, increased nutritional values of plants, significantly improved crop yields and improved environmental monitoring of farming conditions (Srilatha 2011; Razzaq *et al*. 2015). In recent years only research in nanotechnology has focused on interactions between plants and NPs and the effects of NPs on ecology, human health and the food chain; Interdisciplinary knowledge is more needed to evaluate pros and cons of NPs (Tolaymat *et al.* 2015). NPs concentrations can develop toxicity in plants, which originate from seeds and reducing plant growth rate. NPs also play an important

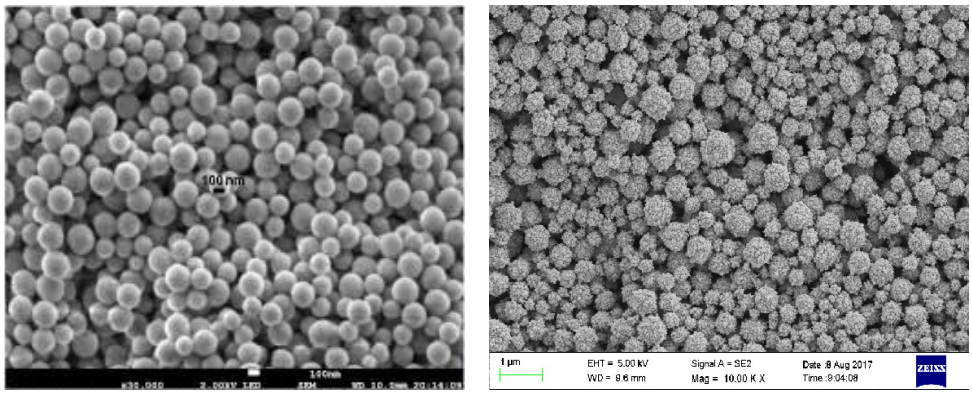
role in plant protection against various types of abiotic factors (Siddiqi and Husen 2016). Nanomaterials have diverse applications in the agricultural field, such as micronutrient delivery systems, pathogen detection, crop improvement and food system protection. Since nanomaterials are in the same size range as bacteria or viruses they can be used as materials for the detection and eradication (Perlatti *et al*. 2013). Plants also show toxic effects based on plant species and the type and concentrations of NPs used for the treatment (Begum *et al.* 2011; Slomberg and Schönfisch 2012). Nanotechnology research and development on nanomaterials interaction with plants are likely to aid and frame the next level of expansion of genetically modified crops, chemical pesticides, animal production and precision farming techniques (Scrinis and Lyons 2007). The role of NPs in plant morphology affects various functions of plant systems. Both negative and positive effects of NPs have been observed on plant growth and activation of growth.

Effects of NPs on seed germination

Water molecules are an important factor for seed germination, a process by which a plant grows which originates from the radical and plumule. The NPs present in the plant growth media and controls the water imbalance by the seed coat and thus affect the germination of seeds. TiO_2 and CeO_2 NPs were found to affect the germination of seeds as well as cotyledon growth time in ten different plant species. Exposure to TiO_2 NPs significantly changed germination rates in five species, although germination increased in some species and decreased in some others. The effects of CeO_2 NPs did not show changes in seed germination in any of the ten plant species (Andersen *et al*. 2016). The high concentrations of TiO_2 NPs affect plant growth of *Oryza sativa* when TiO_2 NPs enter the plant cells that damage the cell wall and plasma membrane (Mirzajani *et al.* 2013). The mechanism behind the change in the germination rate of seeds may be related to the photocatalytic activity of NPs that vary in size and shape (Ma *et al*. 2012). TiO_2 NPs affect growth cell division, cell size, callus induction and hormone rates (Gibberellins and cytokinin) and show significant increase in treated *Rosmarinus officinalis* plants (Golami *et al.* 2018). Another study investigated the effect of ZrO_2, SiO_2, Al_2O_3 and TiO_2 NPs on seed germination of maize plant, with a decrease in the germination percentage of Al_2O_3 and TiO_2, while SiO_2 increased it under all growth conditions. SiO_2 metal NPs had maximum uptake by seeds, followed by TiO_2, Al_2O_3 and then ZrO_2 (Karunakaran *et al.* 2016). The effect of Ag NPs on Germination Percentage of Rice and Pea and 14 Nanomaterials on plant physiology and differentiation of function of 356 maize plants with NPs size. Ag NPs of all sizes (77.5, 111.7, 68.6 and 98.9 nm) showed 100% maximum seed germination in peanut, while Ag NPs of 77.5 and 111.7 nm showed less seed germination in maize and rice, as in comparison with control (Prasad *et al.* 2016). The toxic effects of NPs give rise to decreased plant physiological characteristics such as germination percentage, root elongation, biomass and leaf number (Lee *et al.* 2010). The toxic effects of CuO NPs reduced the fresh weight and root length of *Arabidopsis thaliana* seedlings and the seed germination rates and biomass of rice plants (Shaw and Hussain 2013). The effects of Ag NPs at concentrations (0, 10, 20, 30 and 40 µg mL^{-1}) were investigated at low concentrations (10 µg mL^{-1}), promoting the rate of seed germination in lentils, while higher concentrations of NPs showed negative effects (Singla *et al.* 2019). When wheat plants treated with CuO NPs and were grown in a sand matrix, NPs inhibited plant growth and altered the structure of roots (Dimkpa *et al.* 2012). Treating spinach seeds with 50 µg mL^{-1} of graphene oxide NPs solution induced early and extensive seed germination and increased mass of spinach plants, comparison with 0 and 200 µg mL^{-1} NPs concentration (He *et al.* 2018).

Uptake and translocation of nanoparticles by plants root

There are some conflicting results from many types of research and the NPs effects still depend on particle size. An important interpretation is that plants are influenced by a number of factors such as particle size, morphology and surface response, exposure status of NPs, plant species, root integrity, plant growth stage and rhizome type. One of the most important properties of NPs is the maximum effect of the particles on the root of plants. It is certain size of NPs has a great influence on plant growth in which the growth rate of plants has been observed. The uptake and translocation of NPs cross a series of physical inertial barriers from the root surface to the xylem vessels, firing upward through the root surface cuticle, epidermis, cortex, endodermis, casparian strip and finally transports in shoot through the xylem (Lv *et al.* 2019). The uptake of NPs by plant roots occurs through only two pathways: apoplastic and symplastic pathways. The cell wall of the plant is a complex matrix, where only a few materials pass through the plant cell (Deng *et al.* 2014). Nanofertilizers have an important role in the physiological and biochemical processes of crops by increasing the availability of nutrients, which help to enhance metabolic processes and enhance photosynthesis (Adisa *et al.* 2019). Upon proceeding through the apoplastic pathway, NPs passing through these pores diffuse between the cell membrane and the plasma membrane and are subjected to osmotic pressure (Navarro *et al.* 2008). Many types of NPs reach the endodermis, the symplastic pathway allowing the entry of nanoparticles through the innards of the plasma membrane; this pathway is more important than the apoplastic pathway (Qian *et al*. 2013). The use of µ-XRF and TEM was observed in root of the tobacco plant more than 3.5 nm size Au NPs, but 18 nm Au NPs were based on the root outer surfaces (Sabo-Attwood *et al*. 2012). Using TEM it was found that Au NPs (from 7 to 108 nm) were not directly taken up by roots of *Arabidopsis thaliana* plant (Taylor *et al.* 2014). Using TEM it was observed that SiO_2 NPs up to 200 nm were able to be



(A) **(B)**

Fig 1: Scanning Electron Microscopic image of **(A)** Silica NPs 140 nm (Hernandez *et al.* 2017) and **(B)** Silver NPs 100 to 800 nm (Wang *et al.* 2018).

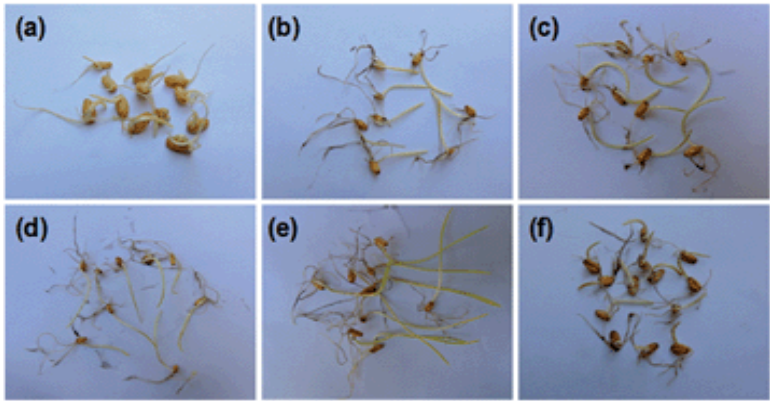


Fig 2: Germinated seeds treated with carbon NPs **(a)** control **(b)** 10 mg L^{-1}; **(c)** 20 mg L^{-1}; **(d)** 40 mg L^{-1}; **(e)** 50 mg L^{-1} and **(f)** 150 mg L^{-1} (Saxena *et al.* 2014).

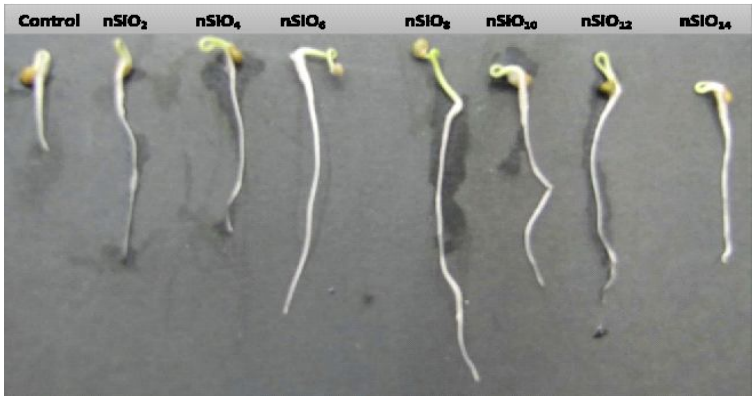


Fig 3: Effect of $nSiO_2$ on seedling growth of tomato (Siddiqui *et al.* 2014).

transported to the roots of *Arabidopsis thaliana* plant, but reduced particles, as the particle size increased (14, 50, 200 nm) in the root (Slomberg and Schoenfisch 2012). In the wheat (*Triticum aestivum*) plant using TEM and µ-XRF, analyzed which evidences that NPs with a primary diameter less than 36 nm deposited in the roots and distributed in whole plant tissue, whereas NPs with diameters in the 36-140 nm range were accumulated in the wheat plant root parenchyma, but did not reach the stele and did not translocation in shoots and NPs larger than 140 nm did not accumulate in roots of wheat plant (Larue *et al.* 2012). Most particles are based on the average size of the original NPs, the uptake of NPs by roots of plant dependent on the minimum size of NPs. The plant root cap is protected by a border cell mucilage layer consisting of root secretion substances. Using X-ray computed nanotomography (Nano-CT) and hyperspectral imaging microscopy (HSI) it was found in *Arabidopsis thaliana* plant roots secreted mucilage that was adsorbed Au NPs positive charge (12 nm) and prevented translocation in other parts of the plant. But

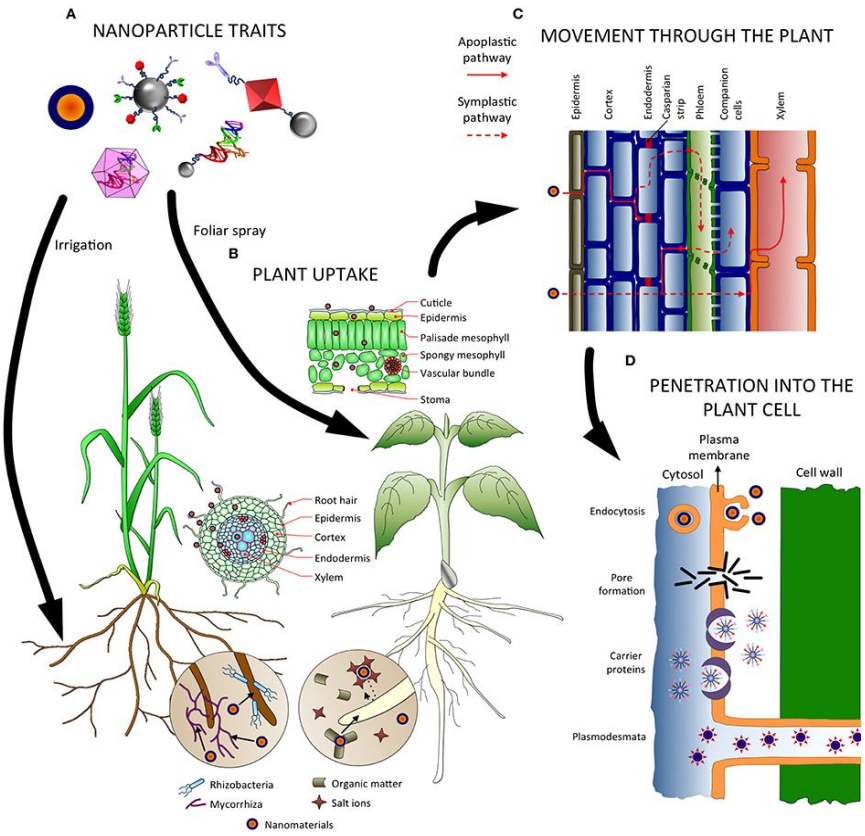


Fig 4: Factors influencing absorption, uptake, transport and penetration of nanoparticles in plants **(A)** uptaken and translocated in the plant **(B)** absorption in vascular tissues **(C)** moving up and down in plant cells **(D)** internalization of NPs inside the cells (Pérez-de-Luque, 2017).

negatively charged Au NPs (12 nm) translocation in apoplast of roots of plant (Avellan *et al.* 2017). The uptake and translocation of TiO_2 NPs (12 nm) were shown from hydroponics media were absorbed by the roots of wheat plants and various growths were recorded. TiO_2 NPs were also observed in parenchyma cells in the root and vascular cylinders after 7 days of exposure, in which NPs were transferred from the media to another part of the wheat plant (Larue *et al.* 2011). Iron oxide (Fe_2O_3) NPs in aqueous media condition in which sown the pumpkin plant and showed NPs uptake and accumulation by the roots and then transported to the leaves through the plant's xylem (Zhu *et al*. 2008). The NPs pass through the epidermis and cortex of plant tissues and enter the intracellular space by the apoplastic pathway and the endosomes confirmed entry of CuO NPs in the plant cells by endocytosis (Wang *et al*. 2012).

Interactions of nanoparticles with plants

Nanoparticles have gained considerable attention in recent years by researchers due to their small architecture and their small size due to significant advances in biomedical, diagnostics and delivery of biomolecules in the cells (Jat *et al*. 2020). The delivery system of agricultural organic molecules, including the transport of DNA molecules or oligonucleotides into plant cells, are important aspects of sustainable agricultural production as well as precision farming (Shang *et al.* 2019). NPs have structures that can be described as materials in the nano-size range. Materials of this size are also found naturally in the environment but the widespread applications and use of different metal NPs in our daily existence are releases directly or indirectly in the surrounding environment (Maurer-Jones *et al.* 2013). Chemically synthesized NPs referred to as engineered NPs due to their unique size, shape and properties of the surface (Dionysiou 2004). NPs are released into the natural system, which interacts with aquatic and terrestrial plants through the atmosphere, water and soil. The NPs interactions are through the uptake, translation and accumulation in the plant species (Rico *et al.* 2011). Different types of nanomaterials such as Au, Ag, Al_2O_3, CeO_2, Cu, CdS, Fe_2O_3, Fe, SiO_2, TiO_2, Zn, ZnO, ZnSe reports their impact on plant physiology and the development of plants (Singla *et al.* 2019). Methods in genetic engineering have changed with the NPs for improvement and made significant in agricultural production, crop protection (Kavipriya *et al.* 2019). Si NPs directly interact with plants and affects the plant and physiology and morphology including the structural color as well as help to improve the yield and growth of plants (Strout *et al*. 2013, Bao-Shan *et al*. 2004). At the physiological level, salinity stress significantly increased root ion leakage and decreased relative water content (RWC), stomata density and Hill reaction, while application of ZnO NPs improved

Table 1: Effects of different types of metallic NPs in plant growth and phytotoxicity.

Types of NPs	Concentrations	Plants	Impacts on plants	Reference
Ag NPs	100 mg kg^{-1}	*Zea mays*	Increased biomass of plants.	Sillen *et al.* (2015)
SiO_2 NPs	500 µl L^{-1}	*Larix olgensis*	Increased root length, lateral roots and plant height.	Bao-shan *et al.* (2004)
Ag Nps	0.05 to 2.5 mg L^{-1}	*Zea mays, Citrullus lanatus* and *Cucurbita pepo*	Enhanced seedling growth, shoot and root length and photosynthesis efficiency of plants.	Almutairi and Alharbi (2015)
Ag NPs	300 mg L^{-1}	*Arabidopsis thaliana*	Inhibit root and leaf growth and photosynthesis rate.	Sosan *et al.* (2016)
Au NPs	10, 50 µg ml^{-1}	*Hardium vulgare*	Enhanced vegetative growth of plants.	Melewska-hendel *et al.* (2017)
Ag NPs	10, 100 mg L^{-1}	*Oryza sativa*	Decreased seed germination and growth rate of plants.	Thuesombat *et al.* (2014)
CuO NPs	500 mg kg^{-1}	*Triticum aestivum*	Increased biomass of the plants.	Dimpka *et al.* (2012)
TiO_2 NPs	100 ppm	*Abelmoschus esculentus*	Increased plant growth and fruit yield.	Reddy *et al.* (2018)
SiO_2 NPs	1 mM	*Lens culinaris*	Enhanced seed germination and growth rate of plants under the salinity condition.	Sabaghnia and Janmohammadi (2015)
Au NPs	10 and 25 ppm	*Brassica juncea*	Increased plant height, stem diameter, pods, seeds and sugar content.	Arora *et al.* (2012)
Fe NPs	1500 mg L^{-1}	*Hordeum vulgare*	Decreased germination rate of seeds.	El-Temsah and Joner (2012)
FeO_3 and ZnO	2 g L^{-1}	*Triticum aestivum*	Enhanced plant height, leaf area and shoot dry weight of plants.	Fathi *et al.* (2017)
TiO_2 NPs	0.5 to 2 g L^{-1}	*Solanum lycopersicum*	Increased production yield and chlorophyll content.	Tiwari *et al.* (2017)
TiO_2 NPs	100, 500 and 1000 ppm	*Cicer aerietinum*	Positive impact on seed germination rate.	Hajra and Mondal (2017)

the Hill response and reduced ion leakage of *Brassica napus* L. plants (Hezaveh *et al.* 2019). Si-NPs was also killed bacterial, fungal and nematode growth infections so disease resistance agents (Rastogi *et al.* 2019).

Foliar uptake of nanoparticles

The Nanoscale delivery system with agricultural nutrients applied to the leaves of tomato plants and nanoparticles penetrate into the leaf and translate in a bidirectional manner, distributing to other leaves and roots (Karny *et al.* 2018). The uptake of NPs by leaves of the plant, mucous layer protect the leaf surfaces from the absorption of NPs in the *Lactuca sativa* plant (Zhao *et al.* 2016). The growth rate of plant organs has been observed to be very different at different life stages and due to this the effect of NPs greatly affects the leaf. Newly grown leaves in plants and undeveloped cuticles in flowers may have a higher probability of NPs entering the leaves and developing from its effects (Honour *et al*. 2009). The high Ag NPs doses mostly bioaccumulate in stevia cells and tissues. Through the multiphoton microscopy allowed these accumulation patterns to be an internalization pathway and have a positive effect on shoot production (Castro-Gonzalez *et al*. 2019). Conditions in leaf entrances of NPs, depending on the exposure pathway, occur under specific conditions but are observed through the stomatal pores of plant leaves (Hong *et al.* 2014). Foliar treatment of Ag NPs on fenugreek plants increased total carbohydrate and protein content when compared with control plants (Sadak, 2019). Silica-silver NPs solution spraying on diseased leaf surfaces and increasing the problem of NPs negative effects on growth and transport in other tissues of plants (Park *et al*. 2006). The cuticle is the most important natural barrier to the entry of NPs into the tissues of the leaves, higher plants are protected by waxy cuticle against water transpiration and control of other substances nearby (Lv *et al.* 2015). There are two routes for NPs solution uptake through the cuticle layers, here non-polar solutes via lipophilic pathway and polar solutes via aqueous pores. The stomatal pathway is confirmed routes for foliar spray of NPs from the leaf surfaces to other tissues of plants (Eichert *et al*. 2008). The four metal oxide NPs (24-47 nm) sprayed on leaves of watermelon plants. They found small size NPs enter the leaves through the stomata using TEM and NPs were detected in the shoots and roots, they passed through the shoots and reached in roots *via* the phloem (Wang *et al.* 2013).

Phytotoxicity of nanoparticles

In the present time, NPs are used in a variety of consumer products such as cosmetics, wound dressings, clothing and

more. After the final use of NPs products, they are being completely dumped into water bodies like rivers and soil. Due to which there is a lot of damage to the environment. Aquatic and terrestrial plants are also exposed to NPs, causing toxic effects in many plant species. The toxicity of MgO and ZnO nanoparticles at concentrations of 250, 500, or 1000 mg L^{-1} for *citrus maxima* to evaluate the potential of their use as nano-fertilizers, in which ZnO nanoparticles produced low-level toxicity in plants (Xiao *et al*. 2019). Airborne NPs have a tendency to attach to leaves and other aerial parts of plants, while roots contact NPs through waterborne or soil materials. NPs penetrate the leaf surface of plants from the bases of trichomes or via stomata and are then transported to the tissues of the plant. NPs deposition has a tremendous impact on the biodiversity of plant species in the ecosystem (Chaudhary *et al.* 2016). Plant growth and antioxidant defense responses differ from plant species. Some studies have shown that toxicity to NPs can also cause differences in seed, size and xylem composition of single-leaf and double-leaf plants (Lee *et al.* 2008). MnOx NPs were treated on the germination of *Lettuce sativa* seeds in a hydroponics medium. MnOx NPs reduced the germination percentage (84% from control to 63%) at high concentrations of 50 mg L^{-1} and were not significantly different from controls. Furthermore, MnOx NPs significantly improved the development of seeding by increasing root elongation (Ruttkay *et al*. 2017). Higher plants try to interact very strongly with their atmosphere and terrestrial environment. These interactions are expected to be influenced by the plant being exposed to different NPs (Navarro *et al*. 2008). ZnO NPs were shown to induce oxidative stress in the concentrations of 500 mg L^{-1} in seedlings of *Glycine max* plants. Plant growth, root hardness and root cell viability were clearly affected by the ZnO NPs strain (Hussain *et al.* 2016). The photosynthetic parameters were changed throughout the development period in cucumber plants. Treating CeO_2 and CuO NPs with 200 mg/L reduced seedling leaf size compared to control, but when mature leaves were measured there was no significant difference between treatments and control (Hong *et al*. 2016). Treatment of TiO_2 NPs had a positive effect on the germination of aged spinach seeds as well as the growth rate of transplanting (Zheng *et al.* 2005). Two different plant species were treated with ZnO NPs at concentrations of 2000 mg L^{-1} and the root elongation of the plant was significantly reduced (Yang *et al.* 2015). The phytotoxicity and genotoxicity were investigated by treating Ag NPs in germinating wheat seedlings. It was observed that 10 mg L^{-1} Ag NPs caused all kinds of changes in the protein, which led to cell metabolism of plants (Vannini *et al.* 2014). In the aquatic plants, growth of *Hydrilla verticillata* was inhibited in the early stages after treatment with ZnO NPs with a high concentration of 1000 mg mL^{-1}, but *Phragmites australis* indicated a decline in plant growth rates after a few weeks

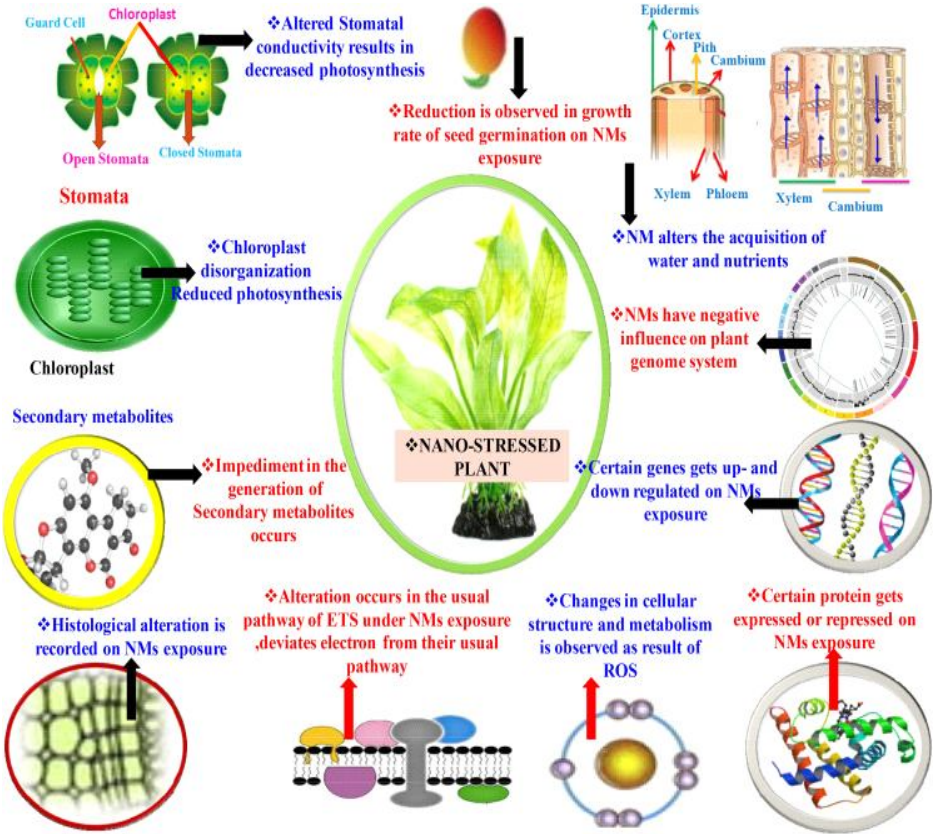


Fig 5: Phytotoxicity of nanoparticles at the cellular level (Tripathi *et al.* 2017).

of exposure. High concentrations of ZnO NPs caused significant phytotoxicity in aquatic plants (Song and Lee 2016). It is also well known that phosphates are widely present in our Earth's atmosphere and are used as most elements of many types of culture media for toxicity testing. A recent study was confirmed that the phytotoxicity of CeO_2 NPs to *Romaine lettuce* plants was determined by phosphate in sand culture media (Zhang *et al.* 2017). The toxicity of Cu NPs was investigated in hydroponic culture media in 10–15 days old Alfalfa and Lettuce seedlings. The size of the plants and the nutrient content of the tissues were significantly decreased, while the activity of the enzyme was altered in both plants (Hong *et al*. 2015). A possible mechanism of phytotoxicity of Ag NPs, which is absorbed by the root surface, disrupted the structure of the thylakoid membrane and reduced the chlorophyll content, an inhibitory effect on the *Arabidopsis thaliana* plant (Qian *et al.* 2013). The phytotoxicity of Al_2O_3 NPs was investigated dependent on concentrations on the root growth and development of *Triticum aestivum* plants. Root elongation was decreased with an increase of NPs concentrations and decreased total protein content, increased peroxidase activity and accumulation of lignin and damage the root cortex of plants (Yanik and Vardar 2015).

Nanoparticles effects on crop improvement

Useful applications of nanotechnology in promoting biological improvement have been applied in a wide variety of aspects. For example, nanotechnology devices are promoting the growth of water-treated seed crops, thereby increasing the yield and improving the quantity and quality of products for many grain crops and cash crops. Nanotechnology is a fast developing stage in the food and agricultural field many types of tools and techniques developed by nanotechnologies for crop improvement. The development of nano chemicals has appeared as promising agents for plant growth, fertilizers and pesticides. In recent years, the use of nanomaterials to control plants, including pests, fungi and weeds, has been considered an alternative solution (Ghidan *et al*. 2019). Reducing crop losses due to environmental and pathogenic stresses, improving resource utilization efficiency and selecting optimal plant traits are major challenges in plant agriculture worldwide (Giraldo *et al.* 2019). With increasing population the demand for food and fiber per unit area is increasing, as a result of which the demand for chemical fertilizer produces more yield than the limited area (Begum *et al*. 2018). The effect of metallic NPs on plant growth and yield suggests the same significant potential methods as either foliar or root nano-fertilizer or nano-insecticide is applied as an application to reduced disease and increase crop production (Servin *et al*. 2015). ZnO NPs increased the protein and starch content and reduced the concentrations of micronutrients such as Cu and Mo in treated cucumber plants (Rico *et al.* 2014). Foliar application of Zn reduced the harmful effects of drought stress on the yield and genotype of the safflower plants. Zn is an essential nutrient for the plant and plays a very important role in plant growth (Cakmak 2008). TiO_2 NPs increase the crop yield of treated *Zea mays* plants by improving the chlorophyll content a, b and carotenoid and anthocyanin content at the concentrations of 0.01% followed by 0.03% (Morteza *et al.* 2013). Agriculture has to face many challenges, such as biological and abiotic stresses, nutritional deficiencies, environmental pollution, reduction in crop yield due to water scarcity; nanotechnology has made promising applications for agriculture. Monitoring, estimating and developing wireless networking and miniaturization of sensors in precision agriculture which has a range of all types of crops (Shang *et al*. 2019). CuO and ZnO NPs exhibit their toxicity upon the germination of seeds of *Lactuca sativa* plants. Cu is a very essential micronutrient for plant growth, Cu NPs positively regulate enzymatic activities by assimilating the tissues of *Zea mays* plants (Adhikari *et al.* 2016). Gold NPs delivery demonstrated a positive effect on seed germination and also increased productivity of *Brassica juncea* plants (Arora *et al.* 2012). Multi-walled nanotubes increased germination rate, increased growth parameters and improved crop production. In addition, multi-walled nanotubes were found to be significantly effective in increasing root cell elongation in wheat plants and biomass production also increased (Wang *et al*. 2012). Multi-walled carbon nanotubes induce faster flow and transport of water by increasing net assimilation of CO_2 and aquaporin transits from exposure to broccoli plants under salinity stress, to reduce stress and increased uptake, There is little change in the properties of the salt-stressed plasma membrane (Martinez *et al*. 2016). Zn and boron nano fertilizers applied to pomegranate leaves and this application increased the yield and quality of pomegranate fruit and also improved the nutrient availability of the plants (Davarpanah *et al.* 2016). The use of inorganic fertilizers on soil and water quality, digestible cover crops can serve as a viable sustainable alternative and legumes also increase the yield of the main crop and a potential source of soil nutrients (Boateng and Tetteh, 2020).

CONCLUSION AND PERSPECTIVE

Nanotechnology is the emerging knowledge of the 21st century in the field of science. Various types of metallic NPs released in our natural environment have a great impact on plant species. Therefore, nanotechnology is becoming very essential today to further help promote ultra-modern farming systems with low environmental impact. Synthesized NPs were used in a wide variety of applications for crop growth and higher yield. It regenerates and accumulates in plant roots, stems, leaves and other parts of the plant and promotes plant growth, respiration, transpiration, biomass production, yield improvement and phytotoxicity. NPs have produced both positive and negative effects on plant growth and development, which depends on the size and shape of NPs. The effect on plant species depends on more or fewer concentrations of NPs. Nanotechnology can transfer-

resistant DNA from plant to another plant against diseases as well as resistant to biotic and abiotic factors.

Author's contributions

DKV reviewed the literature and wrote all parts of the manuscript. SP conceptualized the review and provided valuable guidance. KSK has helped in writing the manuscript. All authors read and approved the final manuscript.

Conflict of interest

Authors declare that there is no conflict of interest for publication of this article.

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