



## Role of nanoparticles in agriculture: A review

Lalita, S Kachhwaha, Priya\*

Department of Botany, University of Rajasthan, Jaipur, Rajasthan, India

### Abstract

Nanotechnology is being looked upon as technology of millennium and appears to have greatly impacted many sectors in a positive way including agriculture. The world population is raising day by day, which lead to increasing food demand. To meet this ever-increasing food demand has led to overuse chemical fertilizers to increase crop yields causing adverse effects on the environment by releasing harmful chemicals in soil, decreasing fertility of soil and also has developed resistance in the pests. Application of nanofertilizers becomes a safer method as compare to chemical fertilizers to boost yield and production in agricultural fields. It also has enormous potential to improve food quality, reduce agricultural inputs, in management of plant diseases, for monitoring soil quality, in water purification etc. Nanoparticles show positive effect on morphological, biochemical, agronomical parameters of the plants with enhanced germination percentage and biomass. It was investigated that some nanoparticles show antimicrobial properties which improves plant disease resistance and increased nutrient uptake efficiency. The review covers the nanotechnology applications in agriculture that are explored by the researchers for improvement of agriculture with reference to selected nanomaterials.

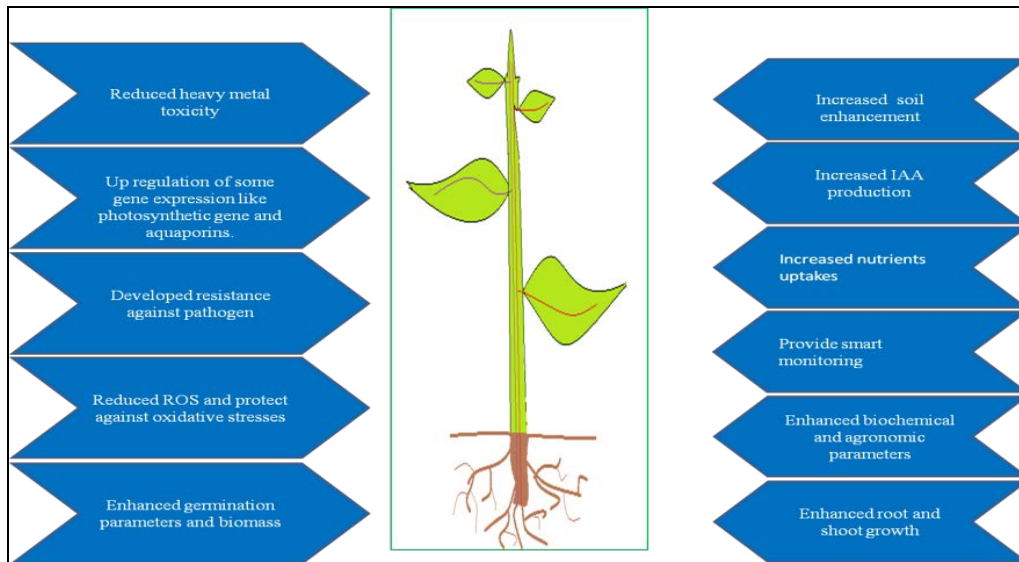
**Keywords:** nanotechnology, nano fertilizer, nanoparticles, soil fertility, antimicrobial properties

### Introduction

Nanotechnology is amalgamation of science, engineering, and technology conducted at the nanoscale. The term nano is derived from Greek word “dwarf”. The very concept of Nanotechnology was first envisaged by Feynman in his celebrated talk on “Plenty of room at the bottom” (Feynman, 1995) [11], but it was Professor Norio Tanaguchi (1974), who introduced the label “nanotechnology” (Bulovic *et al.*, 2004) [7]. The field of nanoscience and nanotechnology deals with study, evaluation and possible application of organic or inorganic materials at a size in the range of few nanometres. Owing to this reduced size these materials have a large surface to volume ratio which confers some special properties to them, elevating their usefulness in various fields. Last few decades have witnessed increase in crop production owing to green revolution but this has also resulted in excessive usage of chemicals to eliminate pests and herbs and to increase crop yields. All of which not only lessens soil fertility but is a big blow to the rich microbe biodiversity of soil, leading to resistance against pest and pathogen and also brought alarming harms to environment and soil ecology. The intervention of nanotechnology in agriculture is quite recent one but in short time nanotechnology has touched all the components of agriculture and lot of improvement through adopting various strategies has been suggested looking at the number of patents and publications coming in this field. Nanotechnology holds special advantages for a developing country like India where there is a big problem of poverty, hunger, population mass and lack of technology advancement. India has already shown its excellence by publishing a large number of research articles covering nano interventions in agriculture (Gogos *et al.*, 2012) [13].

Thus, nanotechnology can provide an insightful impact on agriculture and environment by focusing toward agricultural sustainability, reducing soil pollution, improving yield and

productivity, management of plant diseases, and crop protection. Nanoparticles has been reported to improve growth and germination attributes of many plants by increasing their nutrient uptake from soil, which has led to amelioration of crop yields and food production globally by using precision farming technologies (Khodakovskaya *et al.*, 2009; Joshi *et al.*, 2018) [18, 16]. Concept of “Magic Bullets” as given by Paul Ehrlich, 1908 is truly applicable to nanomaterials whose one dimension at least fall in the nano range and which displays a huge variation in form and structure. These nanomaterials are reported to be prepared from their bulk counterparts, but at a smaller scale there is change in their physical and chemical properties, making them quite distinct from their parent material. Due to their smaller size, they can easily enter into desired cellular location and the elevated surface area facilitates better retention and delivery of desired substance at specific location. Nanomaterials are used as nanobiofertilizer, nanopesticides, nanoherbicides, nanomedicines and for water lustration etc. (Li *et al.*, 2008). Although nanomaterials are of various types but on the basis of dimensions they can be categorized as zero-dimensional e.g., quantum dots which are nano-scaled in all the three dimensions with 1-50 nm in diameter; one-dimensional e.g., single and multi-walled carbon nanotubes etc.; two-dimensionale.g., nanofilms, nanosheets and Nano walls etc. and three-dimensional e.g., nanocomposites etc. (Dolez, 2015) [10]. Out of all these Carbon- and metal-based nanomaterials have been observed to have positive effects on plant growth, germination and development in a dose-dependent manner (Lahiani *et al.*, 2013) [20]. This review focuses on different responses induced by selected nanomaterials in plants.



**Fig 1:** Various responses induced by different nanomaterial's in plants

### Carbon Based Nanoparticles

Carbon nanotubes (CNTs) can be single walled or multi walled containing “sp<sup>2</sup> carbon” atoms as fused benzene rings and have a cylindrical structure and are the member of fullerene family. Single-walled carbon nanotube and multi-walled carbon nanotubes (MWCNTs) are known to influence the physiology, biochemistry of growth and act at genetic level of plants. MWCNTs penetrated tomato seeds and increased germination rate by increased uptake of nutrients (Khodakovskaya *et al.*, 2009) [18]. When plants were treated with MWCNTs mixed with the industrial material Taunit, it was noticed that taunit stimulated the growth of stem and root and caused an increase in peroxidase activity in *Onobrychis arenaria* seedling, when concentration of Taunit was decreased from 1000 to 100 mgL<sup>-1</sup> (Smimova *et al.*, 2012). Oxidized MWCNTs with dimensions in range of 50 to 630 nm have been shown to exert positive effects on wheat root growth, and vegetative biomass but with no marked effect on seed germination as compared with control plant (Wang *et al.*, 2012). MWCNTs deposited on the seed surface such as air spray or augmented in growth medium was reported to enter seed coat of all tested plant species and activate seed germination in barley, and soybean by stimulating aquaporin genes (water channels) that plays a positive role in seed germination (Lahiani *et al.*, 2013) [20]. The effect of functionalized MWCNTs on wheat, peanut and garlic showed positive effect on germination, biomass and water absorption as compared to control (Srivastava and Rao, 2014). MWCNTs enhancing seed germination, biomass and yield production, stomatal density, size of water and food conducting tissues in wheat plant when primed with different concentrations (Joshi *et al.*, 2018) [16]. Single-walled CNTs act as a potential cargo for several molecules into different plant cell organelles. Single-wall CNTs with Fluorescein isothiocyanate (FITC) was observed to translocate effectively into intact cell by fluid phase endocytosis. This indicates the ability of nanotube to carry single-stranded DNA into the tobacco cell in medium with Single-wall CNT/ssDNA-FITC (Liu *et al.*, 2009). The application of CNTs and graphene in tomato seedling increased antioxidant compound responses and activity of

certain enzyme which are involved in reducing stress. The photosynthetic contents, fresh and dry weight of tomato seedling also increased. Therefore, CNTs and graphene can induce stress tolerance in tomato seedling (González-García *et al.*, 2019) [14]. Along with this, recent studies shows that carbon-based Nanomaterials also show antiviral properties, when *Nicotiana benthamiana* plants were sprayed with titanium dioxide (TiO<sub>2</sub>), silver (Ag), C60 fullerenes, and carbon nanotubes (CNTs) at different concentrations for a period of 21 days, CNTs and C60 at a level of 200 mg L<sup>-1</sup> successfully suppressed tobacco Mosaic virus replication and induced up regulation of the defense-related phytohormones (Adeel *et al.*, 2021) [3]. It was also studied that MWCNTs reduced Pb and Cd-induced toxicity by boosting antioxidant defence mechanism and facilitate phytoremediation in *Calendula officinalis* (L.) (Sharifi *et al.*, 2021) [31].

### Magnetic Nanoparticles

Magnetic nanoparticles (MNPs) have shown promising results for their use in agriculture, suitable in the role of ‘postman’ for delivering particular compounds at destined places (Corredor *et al.*, 2010) [8]. In pumpkin plants, MNPs less than 50nm (in diameter) showed successful translocation in the entire plant system (Corredor *et al.*, 2009) [9]. MNPs could be used as capping agent for porous carrier of various chemicals so that their specific localization and uncapping process can be carried out using external magnet, hence releasing the payload at target site. Ferro fluids MNPs coated with tetramethyl ammonium hydroxide (TMA-OH) (as a stabilizing agent) was studied on maize plants (Racuciu and Creanga, 2006) [29] and it was also observed that Chlorophyll a level was increased at low concentration while at higher concentration of ferrofluid, it was inhibited because the excessive iron produced some oxidative stress in leaf cells, and hence chlorophyll a in turn affected photosynthesis in maize plant. The concentration of MNPs also influences enzymatic entities involved in photosynthesis and plant developmental stages so it is necessary to have an idea of suitable concentration range of ferrofluids before designing experiment (Racuciu *et al.*, 2009) [30]. Other than this, the germination parameters,

morphological parameters, total chlorophyll content, carotenoid pigments were increased when engineered MNPs applied hydroponically to the barley plant at doses of 125 or 250 mg/L but higher doses reduced the growth indices. It was also studied that some selected photosystem marker genes displayed upregulation in engineered magnetic nanoparticles-treated leaves of barley as compared with control. The gene expressions were increased proportionally with increasing MNP doses, indicating a positive correlation between MNPs and the photosynthetic machinery which possibly contributed to ameliorate plant growth (Tombuloglu *et al.*, 2020) [39]. In common wheat (*Triticum aestivum* L.), small sized iron oxide nanoparticles in the form of Fe<sub>2</sub>O<sub>3</sub>NMs were found to have positive outcome in terms of growth enhancement compared to those with larger size and thus can be consider employed as nano-fertilizer for agricultural applications (Al-Amri *et al.*, 2020) [5]. Barley plants grown hydroponically with various levels of terbium substituted cobalt ferrite nanoparticles (CoFe<sub>2</sub>O<sub>4</sub> NPs) in the medium showed enhanced growth at three weeks grown seedling stage, may be due to integration of iron within tissues as change in photoluminescence was observed after treatment (Tombuloglu *et al.*, 2021) [38].

Various morphological parameters of *Pisum sativum* along with fresh weight, various pigments, growth of plants was observed to be escalated by the treatment of ZnFe<sub>2</sub>O<sub>4</sub> NP and further enhanced by arbuscular mycorrhizal (AM) fungi (Abdelhameed *et al.*, 2021) [1].

### Zinc Based Nanoparticles

Zinc is a vital micronutrient element required in small amount and which brings about optimum growth in plants and it acts as a warrior in reducing toxic heavy metal toxicity inside the plants. It is also help in recognition and protection against abiotic stress in plants. Zinc oxide nanoparticles (ZnO-NPs) are non-toxic, ecofriendly and reduce reactive oxygen species (ROS) in plants and protect against oxidative stresses (Sheykh *et al.*, 2009) [32]. Increased amounts of antioxidant enzymes were produced when ZnO-NPs were applied to finger millet as spray, this led a increase in proline content (three-fold) in plants under salt stress compared to control, which can be attributed to the mechanism that the NPs have increased the transcription of stress related proteins (Haripriya *et al.*, 2018) [15]. ZnO-NPs also induce seed germination attributes leading to seed establishment in shorter period of time in soil as a consequence of which there is early flowering and escalated leaf chlorophyll contents with improved yields in peanuts (Prasad *et al.*, 2012) [28]. In this sequence, ZnO-NPs synthesised from seed extract of black seeds having dimensions of 24 nm ameliorate seed germination, root and shoot length, weight of seedling, number of leaves in Broccoli (*Brassica oleracea* var. *italica*) compared to the control treated with ZnSO<sub>4</sub> salt solution, in addition high chlorophyll content, phenolics, proline and sugar contents were also observed in Broccoli compared to the control treated with distilled water (Awan *et al.*, 2021) [6, 17]. Beside this, current studies suggested that ZnO NPs also act as an antiviral agent for example the foliar spray of ZnO NPs potentially act as an antiviral agent against To MV in tomato plants (Sofy *et al.*, 2021) [34].

### Silver Nanoparticles

Silver nanoparticles (Ag-NPs) is also playing significant role in the agriculture field such as Ag-NPs affected barley growth at low as well as high concentrations, along with enhancement of protein accumulation in root and leaves, increase in leaf length, fresh weight and surface area was also observed but root growth was inhibited. Diminution of peroxidase activity in leaf was noticed in *Hordeum vulgare* (Khromykh *et al.*, 2015) [19]. Ag-NPs as well induced modest increase in lengths of root and shoot along with chlorophyll and protein content in *Brassica juncea* L. plant (Pandey *et al.*, 2014) [27]. Moreover, in rice (*Oryza sativa*) and Watermelons (*Citrullus lanatus*) Ag-NPs improve germination, growth, yield, and quality when applied by seed priming method (Mahakham *et al.*, 2017; Acharya *et al.*, 2020) [23, 20]. Besides this, AgNPs are also reported to elevate the levels of useful secondary metabolites as reported in *Stevia rebaudiana*, in which at various levels of tested AgNPs there was increase in chlorophyll, physical growth parameters and also Glycosides content increased dramatically, in rosemary plants grown hydroponically when Ag-NPs were sprayed, they behaved as inducers and increased the content of carnosic acid which is a useful medicinal metabolite, in addition to flavonoids (Soltanabad *et al.*, 2020). Ag-NPs are also reported to reduce oxidative stress and Na and Cl uptake by salt-stressed plants and maintain the ionic balance of cells in pearl millet leading to enhanced height, yield, and photosynthesis in a dose-additive manner (Khan *et al.*, 2021) [17]. Green synthesis of Ag-NPs caught the attention of researchers thus green synthesized Ag-NPs using *Moringa oleifera* seeds proved to be potent antimicrobial agent against water borne pathogens (Mehwish *et al.*, 2021) [25].

### Gold Nanoparticles

Gold nanoparticles (GNPs) have unique optical, photo-thermal properties and variety of easily accessible surface functionalization gold nanoparticles find their use as biomedicines opening many new frontiers in this field (Giljohann *et al.*, 2010) [12]. Other than this GNPs also play crucial role in the field of agriculture. Mahakham *et al.* (2016) [24] emphasized that priming maize seeds with phytochemicals-capped GNPs promoted germination attributes and shows fewer damaging effects than gold nanoparticles synthesized by chemical methods. Ndeh *et al.* (2017) [26] also confirmed the biocompatibility of GNPs synthesized by green synthesis method and observed that they can be used as biocarriers in rice plant. The plant parasitic nematodes are one of the important agricultural pests, causing billions of dollars worldwide damage every year. The effect of gold nanoparticles on *Meloidogyne incognita* showed 100 percent mortality, which points towards the strong potency of gold nanoparticles to be used as nematicide for intensive management of the root-knot diseases (Thakur *et al.*, 2018) [37]. Green synthesized GNPs from *Garcinia kola* pulp extract showed antibacterial properties (Akintelu *et al.*, 2021) [4].

### Conclusions and perspectives

Agriculture is a field which has to evolve with time in terms of new technologies that are often introduced for betterment of growth, yield and overall production of crops. The application of nanotechnology in agriculture is quite recent but it has displayed its positive impact in many crops

investigated. The nanoparticles can be used as nano-encapsulation to provide slow and sustainable release of fertilizers in soil which can lead to less use of chemical fertilizer thus, reducing soil contamination and less damage to our environment. Green synthesized nanoparticles are environment friendly and easy to use in agriculture. Many of the green synthesized nanoparticles like that of Gold and silver show antimicrobial properties which helps in management of plant diseases. The delivery of nano fertilizer has given promising results for crop enhancement and protection. Most of the studies in life sciences have reported the effect of nanomaterials on animal and human cells and very little research have been focused on nanomaterials -plant interaction. Many methods of application of nanomaterials on crop plants to investigate their effect on seed germination, biochemical and molecular profiles have been done by several workers. There is lack of consistency in the responses of plants to nanomaterials exposure; methodology for uniform responses at least in the same plant has to be optimized. New research on nanomaterials should include an optimized methodology with specific details, the resources of which should be easily accessible to any researcher or farmer and it should require minimal processing. With the help of this technology, we can increase agriculture resilience by developing technology to increase productivity of plants with a non-GM approach.

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