

NANOTECHNOLOGY: APPLICATION IN THE FIELD OF AGRICULTURE

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Received-21.06.2017, Revised-02.08.2017

Abstract: Indian agriculture, passing through various revolutions, has made appreciable achievement in terms of production & productivity, availability of food grains, horticultural produce, milk, meat & fish which has been possible through technological interventions and critical role played by Indian council of agriculture research (ICAR). Although it continues to be the same to 40 million hectares for the last 40 years, production has increased apparently. The production of food crop has increased 4.5 times, many of the crops which were not known before, have emerged as important, and we have become a leader. Despite numerous challenges and shortcomings, horticulture has exhibited impressive growth. If Indian agriculture has to attain its board national goal of sustainable growth, it is important that the nanotechnology research is extended to the total agricultural production consumption system that is across the entire agricultural value chain. Nanotechnology in agriculture could be used for enhancing the efficiency of the technologies; this includes nanoparticle based disease diagnostics, nano-insecticides for insect pest control, nano-formulation for nutritional studies & various other aspects. Nanomanufacturing makes nanoscale building blocks including nanoparticles, nanotubes & nanostructures. Nanoparticle can be formed by either milling of large particle or by directly chemical synthesis. However, carbon nanotubes and most nanoparticles are synthesized directly from liquid or vapor phases. Chemical & physical vapor phase synthesis is well-established technologies for large scale production of metal, metal oxide and ceramic nanoparticles. The recent development in plant science that focused on the role of nanoparticle in plant growth & development and also on plant mechanism.

Keywords: NPs (nanoparticles), QDs (quantum dots), CNTs (carbon nanotubes), MWCNTs (multi-walled-CNTs)

INTRODUCTION

Nanotechnology, a new emerging field of science, nanotechnological approaches could open up novel application in the field of agriculture & rapidly expanding global industry. Nanotechnology a fastest growing technical field, involves the design, characterization, production & application of structure, devices and system by controlled manipulation of size and shape at nanometer scale that gives novel or superior characteristics property. Nanotechnology in agriculture could be used for enhancing the efficiency of the technologies; this includes nanoparticle based disease diagnostics, nano-insecticides for insect pest control, nano-formulation for nutritional studies & various other aspects. Projected application of nanotechnology in agriculture and food system are pathogen and contamination detection, identify presentation and tracking, smart treatment delivery system. Nanotechnology has been identified all essential in solving many of the problems faced by humans; specifically it is the key to address the foresight nanotech challenges:

- (i) Maximizing the productivity of agriculture
- (ii) Providing abundant clean water globally

- (iii) Making powerful information technology available everywhere.

The word “nano” arises from Greek word “Nanos” meaning dwarf. It denotes a factor of 10^{-9} or one billionth of meter, the term nanotechnology has two meaning i.e. Nanoscale operation technology and molecular nano-technology. Photography & catalysis are example of nanotechnology. The major evolution of nanotechnology is system of Nanosystem and molecular Nanosystem (Roco 2006).

The initial concept of investigating material & biological system at Nanoscale dates to more than 40 years ago (Subramanian *et.al.* 2010) two major approaches are used while working with nanotechnology:

- (i) Bottom up approach
- (ii) Top-down approach

In bottom up approach-different material and devices are constructed from molecular component of their own which are not required to assemble by an external source. Two or more component can be combined to form a new one or to be used as a whole. Some of the example of molecular self assembly are Watson and crick base pairing and enzyme substrate.

In top-down approach, nano objects & material are created by larger entities without bouncing its atomic

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reaction, usually top down approach is practised less as compared to the bottom up approach.

Nanotechnology, mainly consist of the processing of separation, consolidation & deformation of material by one atom or by one molecule (Tani guchi 1974) Nanotechnology will require the integration of chemistry and material science with biology and engineering capabilities to produce unique performance resulting in customer benefits. Nanomanufacturing makes Nanoscale building blocks including nanoparticles, nanotubes & nanostructures. Nanoparticle can be formed by either milling of large particle or by directly chemical synthesis. However carbon nano tubes and most nanoparticles are synthesized directly from liquid or vapor phases. Chemical & physical vapor phase synthesis is well-established technologies for large scale production of metal, metal oxide and ceramic nanoparticles. Carbon black, colour pigments & fumed silica are perhaps the oldest commodity nanoparticles that have been widely used for decades.

The engineered carbon nanotubes also boost seed germination, growth & development of plants (Lahianiet *al.* 2013; Siddiqui & Al-whaibi 2014) however the majorities of studies on nanoparticles to date concern toxicity, comparatively few studies have been conducted on nanoparticles are beneficiary to plants. Research in the field of nanotechnology is required to discover the novel application to target specific delivery of chemicals, proteins, nucleotides for genetic transformation of crops (Torney *et al.* 2007; Scrinis and Lyons 2007) Nanotechnology has large potential to provide an opportunity for researchers of plant science and other fields, to develop new tools for incorporation of nanoparticle into plants that could augment existing functions & add new ones (Cossins 2014) In present review, we discuss the recent development in plant science that focused on the role of nanoparticle in plant growth & development and also on plant mechanism.

Effects of nanoparticles on plant growth & development

When we read many references related to effects of nanoparticle it gives information about how the nanoparticle interact with plants and how they causes changes on their morphology and physiology.

Depending on the properties of nanoparticle efficiency of nanoparticle is determined by their chemical composition, size, surface covering, reactivity and most important the dose at which they are effective (Khodakovskaya *et al.* 2012) Researcher from their findings suggested both positive and negative effects on plant growth and development & the impact of engineered nanoparticle on plants depends on the composition, concentration, size, and physical & chemical properties of engineered nanoparticle as well as plant species (Ma *et al.* 2010)

Effect of silicon di-oxide nanoparticle

Plant growth and development starts from the germination of seeds followed by root elongation and shoot emergence as the earliest signs of growth and development. therefore, it is important to understand the course of plant growth and development in relation to NPs. The reported data from various studies suggested that effect of NPs on seed germination was concentration dependent. The lower concentration of nano-SiO₂ improved seed germination of tomato (Siddiqui and Al-Whaibi 2014). according to suryaprabha *et al.* (2012) nano-SiO₂ increased seed germination by providing better nutrient availability to maize seed. Haghighi *et al.* (2012), in tomato and Siddiqui *et al.* (2014) in squash reported that nano-SiO₂ enhanced seed germination and stimulated the antioxidant system under NaCl stress.

Wang *et al.* (2014) performed an experiment on rice plant treated with QDs, without QDs and with silica coated with QDs, and found silica coated with QDs promoted markedly rice root growth. Nano-SiO₂ enhances the plant growth and development by increasing gas exchange and chlorophyll fluorescence parameters, such as net photosynthetic rate, transpiration rate, stomatal conductance, PSII potential activity, effective photochemical efficiency, actual photochemical efficiency, electron transport rate and photochemical quench.

Effect of Zinc Oxide Nanoparticles

In many studies, increasing evidence suggests that zinc oxide nanoparticles (ZnONPs) increase plant growth and development. Prasad *et al.* (2012) in peanut; Sedghi *et al.* (2013) in soybean; Ramesh *et al.* (2014) in wheat and Raskar and Laware (2014) in onion reported that lower concentration of ZnONPs exhibited beneficial effect on seed germination. However, higher dose of ZnONPs impaired seed germination. The effect of NPs on germination depends on concentrations of NPs and varies from plants to plants. de la Rosa *et al.* (2013) applied different concentrations of ZnONPs on cucumber, alfalfa and tomato, and found that only cucumber seed germination was enhanced. Nano ZnO supplemented with MS media promoted somatic embryogenesis, shooting, regeneration of plantlets, and also induced proline synthesis, activity of superoxide dismutase, catalase, and peroxidase thereby improving tolerance to biotic stress (Helaly *et al.* 2014).

Effect of Carbon Nanotubes

Among the NPs, CNTs have acquired an important position due to their unique mechanical, electrical, thermal and chemical properties. The available data reveal that studies on CNTs have mainly focused on animals and humans (Ke *et al.* 2011; Tiwari *et al.* 2014). Comparatively, there has been scant information available on CNTs and their relation with plants cells and plant metabolism. Due to the unique properties of CNTs, they have the ability to

penetrate the cell wall and membrane of cells and also provide a suitable delivery system of chemicals to cells. The single-walled-CNTs (SWCNTs) act as nanotransporters for delivery of DNA and dye molecules into plants cells (Srinivasan and Saraswathi 2010). However, in various studies researchers have reported that MWCNTs have a magic ability to influence the seed germination and plant growth, and work as a delivery system of DNA and chemicals to plants cells. MWCNTs induce the water and essential Ca and Fe nutrients uptake efficiency that could enhance the seed germination and plant growth and development (Villagarcia *et al.* 2012; Tiwari *et al.* 2014). MWCNTs added to sterile agar medium stimulated seed germination of three important crops (barley, soybean, corn) due to the ability of MWCNTs to penetrate the seed coats as the nanotube agglomerates were detected inside the seed coats using Raman Spectroscopy and Transmission Electron Microscopy (Lahiani *et al.* 2013). MWCNTs improve the root and stem growth and peroxidase and dehydrogenase activity may be due to primary uptake and accumulation of MWCNTs by roots followed by the translocation from roots to leaves (Smirnova *et al.* 2012) that could induce genes expression (Khodakovskaya *et al.* 2012; Lahiani *et al.* 2013; Wang *et al.* 2012). Tripathi and Sarkar (2014) confirmed the presence of water soluble CNTs inside the wheat plants using Scanning Electron and Fluorescence Microscope, and they reported that CNTs induced the root and shoot growth in light and dark conditions. Also, MWCNTs improve water retention capacity and biomass, flowering and fruit yield and increase medicinal properties of plants (Khodakovskaya *et al.* 2013; Husen and Siddiqi 2014). However, inhibitory effect of MWCNTs on plants growth has been reported by many researchers (Tiwari *et al.* 2014; Ikhtiar *et al.* 2013; Begum and Fugetsu 2012; Begum *et al.* 2014). Thus, the effect of NPs on plants varies from plant to plant, their growth stages, and the nature of nanoparticles.

Effect of Gold Nanoparticles

Few studies have been done on the interaction of gold nanoparticle (AuNPs) with plants. Some researchers found AuNPs induce toxicity in plants by inhibiting Aquaporins function, a group of proteins that help in the transportation of wide range of molecules including water (Shah and Belozero 2009). However, Barrena *et al.* (2009) in lettuce and cucumber, Arora *et al.* (2012) in *Brassica juncea*; Savithramma *et al.* (2012) in *Boswellia ovalifoliolata* and Gopinath *et al.* (2014) in *Gloriosa superba* reported that AuNPs improve seed germination. AuNPs improve the number of leaves, leaf area, plant height, chlorophyll content, and sugar content that lead to the better crop yield (Arora *et al.* 2012; Gopinath *et al.* 2014). Christou *et al.* (1988) introduced neomycin phosphotransferase II gene into soybean genome through DNA-coated gold particles.

The positive effect of AuNPs therefore needs further study to explore the physiological and molecular mechanism. Kumar *et al.* (2013) reported AuNPs have a significant role on seed germination and antioxidant system in *Arabidopsis thaliana* and altered levels of microRNAs expression that regulates various morphological, physiological, and metabolic processes in plants.

Effect of Silver Nanoparticle

According to available data a large number of studies on silver nanoparticles (AgNPs) have been documented on microbial and animal cells; however, only a few studies were done on plants (Krishnaraj *et al.* 2012; Monica and Cremonini 2009). As we know, NPs have both positive and negative effects on plant growth and development. Recently, Krishnaraj *et al.* (2012) studied the effect of biologically synthesized AgNPs on hydroponically grown *Bacopa monnieri* growth metabolism, and found that biosynthesized AgNPs showed a significant effect on seed germination and induced the synthesis of protein and carbohydrate and decreased the total phenol contents and catalase and peroxidase activities. Also, biologically synthesized AgNPs enhanced seed germination and seedling growth of trees *Boswellia ovalifoliolata* (Savithramma *et al.* 2012). AgNPs increased plants growth profile (shoot and root length, leaf area) and biochemical attributes (chlorophyll, carbohydrate and protein contents, antioxidant enzymes) of *Brassica juncea*, common bean and corn (Salama 2012; Sharma *et al.* 2012). However, Gruyer *et al.* (2013) reported AgNPs have both positive and negative effect on root elongation depending on the plants species. They reported that root length was increased in barley, but was inhibited in lettuce. Also, Yin *et al.* (2012) studied the effects of AgNPs on germination of eleven wetland plants species (*Lolium multiflorum*, *Panicum virgatum*, *Carex lurida*, *C. scoparia*, *C. vulpinoidea*, *C. crinita*, *Eupatorium fistulosum*, *Phytolaca americana*, *Scirpus cyperinus*, *Lobelia cardinalis*, *Juncus effusus*) and found AgNPs enhanced the germination rate of one species (*E. fistulosum*). AgNP induces root growth by blocking ethylene signaling in *Crocus sativus* (Rezvani *et al.* 2012). The impact of AgNPs on morphology and physiology of plants depends on the size and shape of NPs. Syu *et al.* (2014) studied the effect of 3 different morphologies of AgNPs on physiological and molecular response of *Arabidopsis* and suggested that decahedral AgNPs showed the highest degree of root growth promotion (RGP); however, the spherical AgNPs had no effect on RGP and triggered the highest levels of anthocyanin accumulation in *Arabidopsis* seedlings. The decahedral and spherical AgNPs gave the lowest and highest values for Cu/Zn superoxide dismutase, respectively. The three different size and shape of AgNPs regulated protein accumulations such as, cell-division-cycle kinase 2, protochlorophyllide oxidoreductase, and fructose-1,6 bisphosphate

aldolase and also induced genes expression involved in cellular events; for example AgNPs induced the gene expression of indoleacetic acid protein 8 (IAA8), 9-cis-epoxycarotenoid dioxygenase (NCED3), and dehydration-responsive RD22. Also, AgNPs activated the aminocyclopropane-1-carboxylic acid (ACC)-derived inhibition of root elongation in Arabidopsis seedlings, as well as reduced the expression of ACC synthase 7 and ACC oxidase 2, suggesting that AgNPs acted as inhibitors of ethylene perception and could interfere with ethylene biosynthesis.

Role of Nanoparticles in Photosynthesis

We know that photosynthesis is a key process for plants on earth that changes light energy to chemical energy. Plants convert only 2–4 % of the available energy in radiation into new plant growth (Kirschbaum 2011). Nowadays, scientists are trying to improve this low efficiency of vascular plants by manipulating techniques and gene manipulations. For speed-up of plant photosynthesis and turbocharged crops, scientists are working with Rubisco, an important enzyme for photosynthesis process to catalyze the incorporation of carbon dioxide into biological compounds. Recently, Lin *et al.* (2014) developed new tobacco plants by replacing the Rubisco gene for carbon-fixing in tobacco plant, with two genes of *cyanobacterium* *synechococcus* elongates; these new engineered plants have more photosynthetic efficiency than native plants. Also, in the field of nanobiotechnology, researchers want to develop bionic plants that could have better photosynthesis efficiency and biochemical sensing. Giraldo *et al.* (2014) reported that embedded SWCNTs in the isolated chloroplast augmented three times higher photosynthetic activity than that of controls, and enhanced maximum electron transport rates, and SWCNTs enabled the plants to sense nitric oxide, a signaling molecule. They suggested that nanobionics approach to engineered plants would enable new and advanced functional properties in photosynthetic organelles. Also, they said that still extensive research would be needed to see the impact CNTs on the ultimate products of photosynthesis such as sugars and glucose. Also, Noji *et al.* (2011) reported that a nano mesoporous silica compound (SBA) bound with photosystem II (PSII) and induced stable activity of a photosynthetic oxygen-evolving reaction, indicating the light-driven electron transport from water to the quinone molecules, and they suggested that PSII-SBA conjugate might have properties to develop for photosensors and artificial photosynthetic system. SiO₂NPs improves photosynthetic rate by improving activity of carbonic anhydrase and synthesis of photosynthetic pigments (Siddiqui *et al.* 2014; Xie *et al.* 2012). Carbonic anhydrase supplies CO₂ to the Rubisco, which may improve photosynthesis (Siddiqui *et al.* 2012)

CONCLUSION AND FUTURE PROSPECTS

No doubt, nanotechnology is an evolutionary science and has introduced many novel applications in the field of electronics, energy, medicine, and life science. However, due to their unique properties, a number of researches have been done on the toxicological effect of NPs on plants, yet research focusing on the realization of the beneficial effects of NPs on plant remains incomplete. Few studies have shown positive effect of NPs on plant growth and development. It is evident from compiled information that effect of NPs varies from plant to plant and depends on their mode of application, size, and concentrations. This chapter reveals that the research on NPs, essentiality for plants, is in the beginning; more rigorous works are needed to understand physiological, biochemical, and molecular mechanisms of plants in relation to NPs. Also, more studies are needed to explore the mode of action of NPs, their interaction with biomolecules, and their impact on the regulation of gene expressions in plants.

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