A novel approach to utilise nanopartilees on agricultural sector: A brief review

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Abstract

Interactions of plants with NPs include uptake, translocation and accumulation of NPs, depending on the nature of plant species as well as the shape, size, type, chemical composition, fictionalization and stability of ENPs. Most of the studies deal with negative effect on growth and development of seedlings. So far, germination, biomass assay, antimicrobial, anatomical as well as few histological studies has been done by using varieties of NPs. This interaction is very important as the NPs which are stored within the plants;-get transferred from plants (producers) to animals (consumers).
Research shows that not only the negative aspect, but NPs can have great impact on positive aspects on different fields, of which we highlight mainly on the agricultural sector.

Key words

Nanoparticles; Agriculture; positive impact; Biomass production; nanofertilizer

Introduction

Indiscriminate applications of NPs in various industrial as well as in household products create a new challenge to all the living beings as to how they react with these NPs externally as well as internally. In recent years researchers have studied how different types of NPs interact with varieties of plant species along with animals, microbes and others. In general NPs after incorporation and bioaccumulation within biological systems cause intracellular and molecular level changes leading to acute toxicity as well as mutation in gene level [1-3]. However, details of molecular level studies are still in root level.

Although fertilizers are very important for plant growth and development, most of the applied fertilizers are rendered unavailable to plants due to many factors, such as leaching, degradation by photolysis, hydrolysis, and decomposition. Hence, it is necessary to minimize nutrient losses through fertilization, and to increase the crop yield through the exploitation of new applications with the help of nanotechnology and nanomaterials. By the application of carbon nano tubes in plants, scientists prove the plants' ability to harvest more light energy by delivering carbon nanotubes into chloroplast, and also carbon nanotubes could serve as artificial antennae that allow chloroplast to capture wavelengths of light which is not in their normal range, such as ultraviolet, green, and near-infrared [4]. It is also proved that engineered carbon nano tube (both multiwall and single walled) also boost seed germination percentage, plant growth and biomass production [4, 5]. However, few studies have been conducted on NPs which are beneficiary to plants in comparison to their toxic effect. Recently introduction of nanofertilizers in agricultural and horticultural sectors is no doubt a big challenge to the researchers. Nanofertilzers or nano-encapsulated synthetic nutrients have the capability to regulate plant growth and increased biomass production by controlled release of chemical fertilizers and on demand release of nutrients respectively [6, 7]

However, there are also some reports on positive aspects of few NPs on different plant species. Target specific delivery of nucleotides, proteins, chemicals for genetic transformation of crops has also been well studied [8, 9].

Our effort is to present a clear picture on and only on the beneficial aspects of various NPs on plant system so that the applications of these particles on agriculture as well as horticultural sector can become fruitful in near future.

Types of nanoparticles:

The unique properties of NPs encourage scientists to engineer different kinds of NPs (ENPs). The ENPs have immense possibilities and can be put to use in every aspect of our daily lives [10].

Based on their composition, ENPs can be classified into four major groups.

1. Carbon based materials viz. fullerene (C_{70}), fullerol [$C_{60}(OH)_{20}$] and carbon nano tubes (CNTs) like single walled carbon nano tubes (SWCNTs) and multiwalled carbon nano tubes (MWCNTs).
2. Metal based NPs like Zn, Au, Ag, Cu, Fe NPs and metal oxide NPs like ZnO, TiO_2, Al_2O_3, Fe_3O_4, CeO_2 etc [11].
3. Dendrimers- the nano-sized polymers built from branched units, capable of being tailored to perform specific chemical functions [12].

4. Composite NPs with different morphologies such as spheres, tubes, rods, prisms [13, 14]

The rapid development of ENPs also causes release of these NPs in the environment [15-23]. Fig 1 shows the categories of NPs present in the environment.

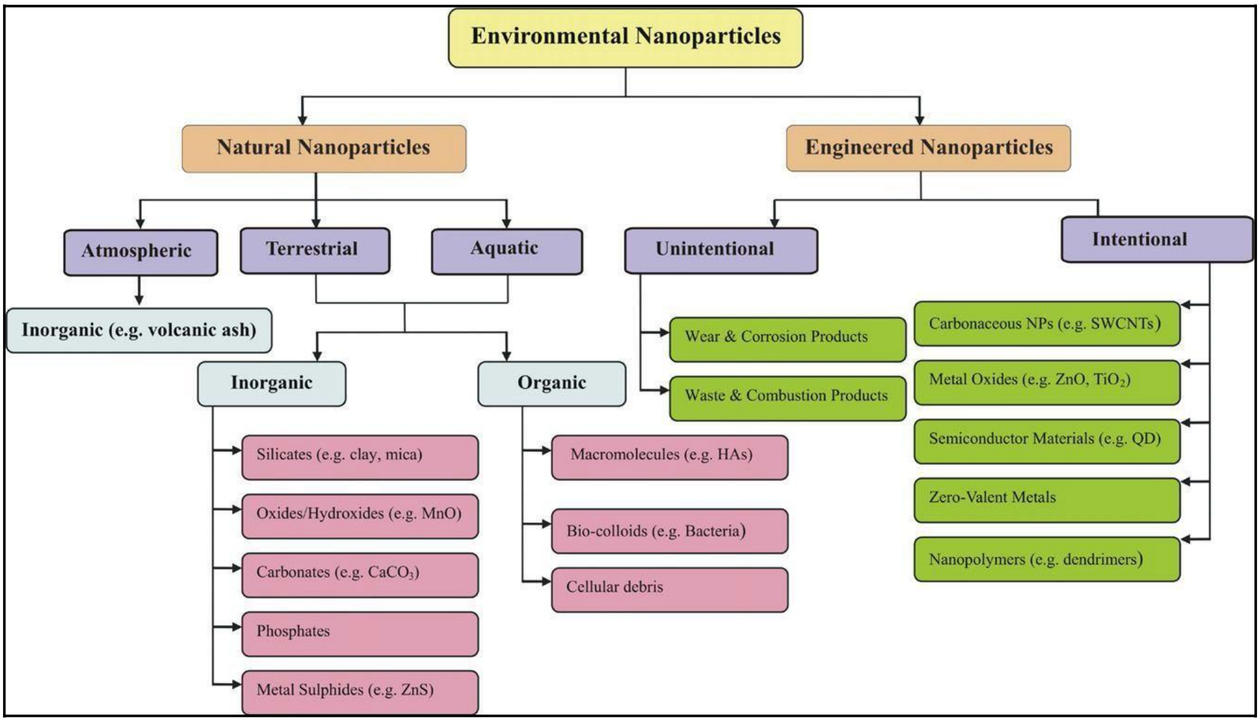

Fig. 1. Categories of nanoparticles resent in the environment. Adapted from I. Bhatt and B. N. Tripathi (2011) Chemosphere 82, 308 – 311

Details of positive aspects of ENPs on plant system:

1] Enhancement of growth and biomass production:

Investigations are increasingly being focused on carbon nano tubes (CNTs) in contrast to other nanoparticles due to their biocompatibility and membrane permeability [11, 12]. In general NPs after incorporation and bioaccumulation within biological systems cause intracellular and molecular level changes [13-15]. Penetration capability of CNTs through hard seed coat has very recently been reported by Mariya Khodakovskaya et al [16]. They reported that in presence of carbon nano tubes tomato seeds grow faster than seeds grown in absence of CNTs due to enhancement of water uptake process as CNTs penetrate the seed coats. Recently in many studies researchers have proved that MWCNTs have a great role in overall plant growth and biomass production [17, 18]. Lahiani et al (2013) have shown that MWCNTs can penetrate the seed coat of corn, soyabean and barley and regulated gene expression of several water channel protein of the above mentioned seeds and thereby enhances the water uptake machinery. The maximum germination rate was observed with OMWCNTs in case of tomato, Bt cotton, *Brassica,* Rice and *Phaseolus*. [19-22]. We have also studied and reported the effect of MWCNTs and OMWCNTs on membrane permeability, enhanced germination rate growth and biomass production of mustard plants [23]. Uptake and accumulation of MWCNTs by root followed by translocation from root to leaves that finally improve the root and stem growth was noticed by [24, 4, 25] other researchers.

2] Beneficiary roles of ENPs on Photosynthesis:

To meet the growing energy need of the developing country scientists are involved to investigate new techniques to enhance the natural energy conversion efficiency in various ways. In the isolated chloroplast embedded SWCNTs facilitate three times higher photosynthetic activity than control and maximum electron transport rates also increase [26, 27]. SiO2 NPs can improve photosynthetic rates by improving activity of carbonic anhydrase and synthesis of photosynthetic pigments [28, 29]. SiO2 nano do this by increasing photosynthetic rate, transpiration rate, stomatal function, effective photochemical efficiency, PSII activity, gaseous exchange and enhance electron transport mechanism [28]. Under stress condition nano SiO2 also increases the chlorophyll content along with proline accumulation [30]. Research of Raliya & Tarafder, 2013 [31] also showed that ZnO NPs can enhance biomass production, chlorophyll content, enzymetic activities, rhizospheric microbial population in *Cyamopsis tetragonoloba.*

MWCNTs can improve the water retention capability, enhancement of biomass, flowering and fruit yield and also some medicinal properties [32,28]. Tripathi and Sarkar (2014) [33] reported that CNTs can induce root and shoot growth in light and dark condition in wheat plant and they also noticed the presence of water soluble nanoparticles inside the plant body by using scanning and fluorescence microscope.

In another research it was observed that Au NPs can enhance leaf numbers, plant height, chlorophyll content, sugar content etc which finally improve the biomass production of the plant [34]. It has been proved that exogenous application of nano TiO_2 can increase photosynthetic rate, water transport machinery and overall transpiration rate [35]. TiO2 nano can also protect chloroplast from aging against long time illumination [36, 37].

3] Positive effect of ENPs on seed germination and biomass production:

It has been proved in various studies that MWCNTs and OMWCNTs have a magic ability to influence seed germination rate and plant growth. [38]. Presence of MWCNTs inside the seed coat in the agglomerate form were detected by using Raman Spectroscopy and Transmission Electron Microscopy [4]. MWCNTs also have the capability to regualate the gene expression of water channel proteins in soybean, corn and barley seeds coat. The maximum germination rate in tomato, hybrid Bt cotton, *Brassica juncea*, *Phaseolus mungo* and rice was observed with MWCNTs [39-41, 5].

SWCNTs can initiate root elongation in Allium cepa and Cucumis sativus [42]. Khodakovaskaya et al, 2012 [43] reported that 5 – 500 µg/mL dose of MWCNTs can induce growth of *Nicotiana tabacum* cell culture by regulating marker genes for cell divisions (*CycB*), cell wall formation (*NtLRX1*) and water transport (aquaporin, *NNtPIP1*). Wang et al [44] reported oxidized- MWCNTs significantly enhanced cell elongation in the root system and promoted dehydrogenase activity.

It was observed in case of *Vigna radiata* that suspension or foliar application of ZnO NPs at a dose of 20 ppm was effective for biomass enhancement [45]. Application of Sulphur NPs is also helpful for dry weight enhancement of *Vigna radiata*. Prasad et al at 2012 noticed that application of ZnO NPs at a particular dose enhance germination percentage, overall biomass and fruit yield of Arachis hypogaea as well as increase dry weight while applied on *Vigna radiata*. Another study revealed that lower dose of ZnO NPs increased germination and growth in onion [46].

Application of 60 ppm AgNPs on *Phaseolus vulgaris* is beneficial in respect to root-shoot length and overall dry weight enhancement [47]. Kumar et al, 2013 [48] observed that application of GNPs on Arabidopsis thaliana increased germination percentage and root length. Savithramma et al, 2012 [49] observed that green synthesized AgNPs enhanced seed germination rate and growth of seedlings of *Boswellia ovaliofoliolata.*

Another study revealed that application of aluminium oxide NPs on *Arabidopsis thaliana* enhances root length [50]. Alumina NPs can also enhance biomass accumulation and root length in Lemna minor [51]. Application of iron oxide nanoparticles on Glycine max increased production yield [52] while ZnFeCu-oxide suspension enhance biomass of *Vigna radiata* when applied in proper dose [67].

TiO_2 NPs enhanced seed germination and promoted radicle and plumule growth of canola seedlings [53]. It was also reported that TiO_2 NPs can enhance germination rate in case of *Foeniculum vulgare* [54].

4] Increase of enzymatic activities on plant system:

Most of the NPs that show beneficiary effect on plant system can make direct or indirect effect on enzymatic system. Nano-anatase TiO_2 activates rubisco activase mRNA expression [55] in *Spinacia oleracea*. Foliar spray of this NPs solution on spinach enhances photosynthetic carbon reaction rate and also make a great impact on oxygen evolution mechinary by overexpressing rubisco carboxylase and rubisco activase [56-59]. Yang et al, 2006 [60] also observed that application of nano-anatase TiO_2 induced several enzymatic action like nitrate reductase, glutamate dehydrogenase, glutamine synthase, and glutamic-pyruvic transaminase that helps the plants to absorb nitrate during nitrogen metabolism of the spinach plant. During oxidative stress conditions application of Ag NPs can delay the senescence of stressed seeds due to arrival of reactive oxygen species (ROS) which has the capability to delaying senescence due to arrival ofreactive oxygen species during oxidative stress condition [61]. MS media enriched with ZnO NPs can induce proline synthesis, and also induce the activity of catalase, peroxidise, superoxidase dismutase and by this way improve the biological stress tolerance capability [62].

5] Positive involvement of NPs in gene level:

It was observed that neomycin phosphotransferase II gene was introduced into soyabean genome through DNA-coated gold nanoparticles that can alter the level of micro RNAs which have the capability to regulate various of metabolic and physiological processes in plants [63, 64]. ZnO in its nano forms can induce somatic embryogenesis and regeneration of plantlets and induce shoot formation [64]. However, more researches need to be done in this area to clarify the involvement of NPs in gene level.

6] Utilization of NPs as nanofertilisers:

Capability of ENPs to enhance germination percentage and plant growth rate may reduce positively the huge utilization of inorganic fertilizers to crop field. The NPs that can enhance germination percentage and overall plant growth can be used to increase the vigour of plants like crop plants, foliage rich plants viz. spinach, coriander leaves etc, plants used for fodder and biofuel like Jatropha and others , plants used for waste management, metal indicators etc. The effect of carbon coated magnetic nanoparticle provides biocompability and large absorption surface in living plants as C*ucurbita pepo* and the results showed the presence of nanoparticles both in the extracellular as well as within the cell [65].

7] Involvement of NPs in plant disease prevention:

Nanoparticles have some specific effect on bacteria and fungi colony. However, these effects are suppressive and depend on effect of stimulus. It has been observed that $CuSo_4$ and $Na_2B_4O_7$ in their nanoforms can effectively control rust disease of peas. Green synthesized silver nanoparticle (synthesized from *Solanum tricobatum* and *Ocimum tenuiflorum* leaf extracts) has antimicrobial activity against *E. Coli and S. Aureus* [66]. Scientists have already proved that NPs have very strong and definite effect on fungi and bacterial colonization. Abd El-Hai et al proved that zinc and magnesium like microelements can suppress the charcoal rot and damping of disease of sunflower [67].

Now a days nanopestisides can effectively control plant pathogens in its minute amount and can give satisfactory effect on disease control. In near future these nanopestisides would reduce the adverse effect of marketed pesticides, fungicides etc [68].

Conclusion:

We have very briefly reviewed here the research works being conducted on the effect of ENP on (i) enhancement of growth and biomass production (ii) their beneficiary role on Photosynthesis: (iii) their positive effect on seed germination and biomass production: (iv) increase of enzymatic activities on plant system: (v) their positive involvement at the gene level (vi) their utilization as nanofertilisers and finally (vii) their involvement in plant disease prevention**.**

The overall perusual analysis revealed that NPs have significantly positive role on different aspects of agriculture. They are able to solve many challenges in agricultural sectors. Enhancement of enzymatic activities due to incorporation of NPs may increase activity of biological pathways inside the plant system that further gives overall positive impacts on agricultural fields. The NPs that can enhance chlorophyll content, leaf numbers and total photosynthetic rates can be used to increase the vigour of plants like crop plants, foliage rich plants viz. spinach, coriander leaves etc, plants used for fodder and biofuel like Jatropha and others , plants used for waste management, metal indicators etc.

In an agriculture dependent country like India, any kind of positive strategy for agricultural purpose will be extremely helpful to farmers. Capability of ENPs to enhance germination percentage and plant growth rate will positively reduce the huge utilization of inorganic and toxic fertilizers to crop field.

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