

Current Trends of Engineered Nanoparticles (ENPs) in Sustainable Agriculture: An Overview

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Abstract

Nanotechnology is an interesting area of multifaceted research in agricultural perspective. This technology incorporates the manufacturing of material at nano level. Nanoparticles (NPs) have now become an integral part of research because of their unique features like their size, shape and surface reactivity. In agriculture sector engineered nanoparticles (ENPs) i.e., metal NPs, metal oxide NPs and Carbon Nano Tubes (CNTs) etc has been used in the form of nanofertilizers and nanopesticide/ herbicides. Therefore, the appropriate use of nanoparticles could provide a proficient sustainable platform to achieve the food requirement of global massive population. As of the application of nanotechnology to agriculture and food industry is outturn in enhanced crop yield with better food quality as well as safety. In spite of the significances of nano-material, negative outcomes should also be taken in consideration before applying it on a large scale.

Keywords: Sustainable agricultural; Engineered nanoparticles (ENPs); Crop yield; Food quality; Safety

Introduction

Nanotechnology is an enthralling scientific field, which offers multidirectional research in the area of agriculture as well as biotechnology, now its time to unraveling the novel applications with their mode of action [1]. Now, current agricultural sector demands a continuous innovative research to meet out the food requirement of enormously increasing population, therefore nanotechnology plays a promising role by influencing crop production in this modern technical era [2]. Agriculture is the backbone of the majority of developing countries; approximately 60% of population depends on agriculture for their livelihood [3]. Nanotechnology influences the agriculture productivity with the relevance of Nanofertilizer, nanopesticides or nanoherbicides and nanocoating, these are smart delivery system to plants, also the various industries creating formulations with nanoparticles (100-250 nm) to enhance their actions by increasing nanoparticles solubility in water [3,4] (Figure 1). The synthesis of engineered nanoparticles (ENPs), processing of nanomaterials, and their applications comes under the area of nanotechnology and therefore excellent efforts have been made to synthesize biogenic engineered nanoparticle (ENPs) [5,6] with a unique blend of antibacterial and photocatalytic properties for critical applications [6]. Nanomaterials properties vary from the bulk materials of same composition. The synthesized nanoparticles provide large specific surface area and also bears huge amount of atom for chemical reactions [7]. Engineered nanoparticles have distinctive physicochemical properties rather than other particle that exist in nature [1,8]. These are the two dimensional particles that generally formed between 1-100 nm range [9,10]. Effectiveness of ENPs on different plants are determined using different parameters such as chemical composition, specific size, surface covering, reactivity, and their effective dose regarding plants [11]. The plenty of scientific studies, reported that the synthesized nanoparticles have positive and negative consequences on the plant growth that depends on the different size and other parameters of engineered nanoparticles [1,12]. Much progress has already been accomplished in this area over the past decades however, proficient compilation in the form of grave

review on various aspects of this topic has not been explored properly. This review therefore, attempts to provide the plenty of information based on several studies together at one place.

Applications of Nanoparticles on Agriculture

Nanotechnology cannot be confused as the one technology but it is a group of miscellaneous technologies working at the nano level [13]. Alone in the agriculture prospects there are extensive potential applications of nanotechnology, for instance; nanotechnology facilitates release of chemicals to modern agricultural system (Figure 1) and also aid nano-sensors for the observation of environmental stress [14], use in maintaining crop setting, and combating against the environmental stresses including diseases via enhancing plant qualities [13,15]. According to Parisi et al. [16] european commission appraised that in developed countries, pesticide formulations and nanosensors are the main applications of nanotechnology which are very useful in applied and sustainable agricultural practices. As the nanotechnology facilitated applications are promising to the sustainable crop production, it also delivers multiple stresses in the way of plant growth and development. Numerous positive and negative impacts of nanoparticles were studied by several workers in the area of agricultural sector, Fraceto et al. [17] reported about some recent studies that focuses on the positive

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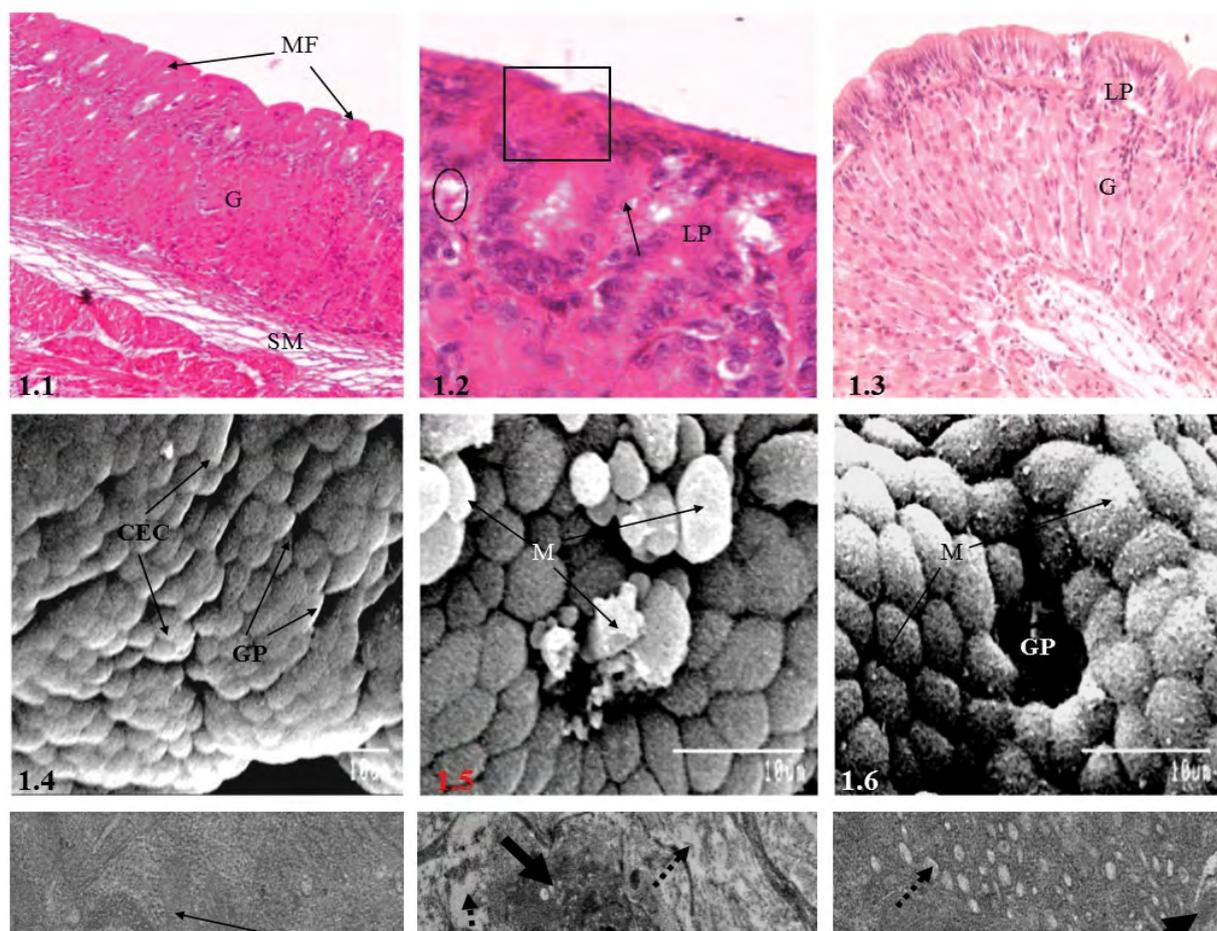


Figure 1: Nanoparticles (NPs) (metal NPs, Metal oxide NPs and carbon nanotubes) at optimum dose increases chlorophyll content, release of required chemicals, nutrient uptake, NPs solubility, cell elongation, germination rate, growth parameters, microbial activities and crop productivity [3,4,12,15-17,20-41], while at high dose cause phytotoxicity by reducing crop yield and productivity [26-33,38].

potential side of nanoparticles on agricultural area. Carbon nanotubes and nanoparticles of Au (gold), SiO₂ (silicon oxide), ZnO (zinc oxide), and TiO₂ (titanium oxide) nanoparticles by increasing essential metal-nutrient uptake reported to enhance the plant development [17,18]. In the support of above statement, Morteza et al. [19] suggested that TiO₂NPs enhanced crop yield of corn (*Zea mays* L.) by improving the chlorophyll (a and b), carotenoids and anthocyanins contents with their concentration of 0.01% and 0.03% respectively. Similar studies were elaborated with positive effects of TiO₂NPs in canola (*Brassica napus*) [20], *Solanum lycopersicum* (L.) and *Vigna radiata* (L.) [21]. While study by Da Costa and Sharma [22] found phytotoxicity of TiO₂NPs on *Oryza sativa* which was observed through decrease in seedling growth, photosynthetic activity and biochemical processes at their elevated concentration (1000 ppm). Tripathi et al. [23] elaborately reviewed about the number of phytotoxicity created by manufactured nanoparticles in different plants on the ground of physiological, biochemical, genetic and molecular. Different negative effects were also reported by Song et al. [24] on Seeds of *Brassica napus*, *Lactuca sativa* and *Phaseolus vulgaris*. Study on maize seed germination with ZrO₂ (zirconia), SiO₂ (silica), Al₂O₃ (Alumina) and TiO₂ (titania) nanoparticles resulted in exhibition of reduced seed germination at the same time SiO₂NPs and zirconia (ZrO₂) increased seed germination and root elongation, whereas root inhibited by the application of Al₂O₃ and TiO₂ [25]. In the case of ZnO NPs, it has significantly influences the growth, yield, and zinc content

of maize grains [26]. Analogous results were obtained by Adhikari et al. [27] on maize plant. On the contrary, ZnO NPs have reported to exhibit phytotoxicity in corn (*Zea mays* L.) and cucumber (*Cucumis sativus* L.) [28]. Most of the silver nanoparticles (AgNPs), based studies showed the negative implications on growth and development of agricultural crop [29] including the modification at molecular level in different plant species such as Mung bean (*Vigna radiata* L.) [30], *Arabidopsis thaliana* [31,32], and *Oryza sativa* [33,34]. Similarly, Da Costa and Sharma [35] propounded exogenous application of CuO NPs (copper oxide) in rice (*Oryza sativa*, var. Jyoti) that resulted in decrease in germination rate, growth parameters and biomass. Simultaneously, Liu et al. [36] documented that CuO NPs and ZnO NPs display toxicity on the germination of lettuce (*Lactuca sativa*) seeds. On the other side Cu being an essential micronutrient, Cu NPs positively influence growth of maize (*Zea mays* L.) plant by assimilating into the routes of plant and regulating the enzymatic activities [37]. Mn and FeNPs delivery reported to display positive impacts on the seed germination and were also enhanced agronomic productivity. In accordance with most of the experimental report metal nanoparticles and their oxides AgNPs (*Hordeum vulgare* L.) [38], AuNPs (*Brassica juncea*) [39], TiNPs (wheat) [40], Fe₃O₄NPs (iron oxide) (wheat) [41] positively responds to the crop productivity. In case of carbon based nanomaterials Carbon Quantum Dots (CQDs), Graphene Quantum Dots (GQDs), Graphene Oxide (GO), and Single-Walled Carbon Nanotubes (SWCNTs) an

experimental study on bean sprout revealed phytotoxicity in a dose dependent manner [42]. Whereas, a plenty of studies on carbon nanoparticles or carbon nanotubes on different plants species such as, tomato (*Lycopersicon esculentum* M.) [43], mustard (*Brassica juncea*) [44] and rice (*Oryza sativa* L.) [45] manifested enhance germination rate, increase in growth parameters resulted to improve crop production. Furthermore, multi-walled nanotubes (o-MWCNTs) were found effective in increase of root cell elongation in wheat plant and also played an important role to step up dehydrogenase activity thus increase in growth and biomass production [46]. Nanoparticles can also be incorporated into the preparation of pesticides, insecticides and insect repellants for securing the crop against insect and pest [47-49]. Relevant to the above statement, study reveals the nature of non-functionalized and amino-functionalized multiwall Carbon Nanotubes (CNT) in controlling the pesticide availability to lettuce (*Lactuca sativa* L.) seedlings. According to which Non-functionalized CNT (88% and 78%) and amino-functionalized CNT (57% and 23%) was found to reduce the root-shoot pesticide content respectively. Therefore, in respect to agricultural field it suggests an imperative application of engineered nanomaterials for leafy vegetables [50]. Nanoparticles not only helps in improving crop yield by increasing mineral availability (Maize) [51], but also improve the crop yield by alleviating the heavy metal toxicity, UV-B induced stress and other abiotic stresses. As documented by Tripathi et al. [52] SiNPs (silicon) effectively reduce UV-B induced stress in wheat seedling by the enhanced antioxidant mechanism. Si NPs has been reported to potentially remove chromium [Cr(VI)] mediated toxicity in *Pisum sativum* (L.) seedlings by suppressing the Cr accumulation and increasing nutrient availability to the plant [53]. Si NPs is also found to be more efficient than Si in removing different level of arsenate (25 and 50 μM) mediated toxicity in maize cultivar and hybrid by increasing ascorbate-glutathione cycle (AsA-GSHcycle) components and reducing oxidative stress and arsenate accumulation [54]. According to Siddiqui and Al-Wahaibi, [55] Nano-silicon dioxide (nSiO_2) significantly effects seed germination of tomato (*Lycopersicon esculentum* Mill.). In addition to metal and metal oxide nanoparticles, fungal cell wall polymer (chitosan) based nanoparticles (CWP-NP) has been proved to enhanced yield of tomato by protecting the plant against *Fusarium oxysporum* f. sp. *lycopersici* infected wilt disease [56]. Multi-walled carbon nanotubes exposed to broccoli under salinity stress reported to induce water uptake and transportation by increasing the net assimilation of CO_2 and aquaporin transduction, also slightly changes the properties of salt stressed root plasma membrane to alleviate the stress and increasing growth [57]. Nanomaterials have the potential to respond with soil biota. TiO_2 NPs, multi walled CNTs (MWCNTs), and CeO_2 NPs (Cerium oxide) applied in agricultural soil divulges to fix the biological nitrogen by rhizobia and arbuscular mycorrhizal (AMV) fungi on red clover [58].

Nowadays, nanofertilizers have become immensely interesting area of study for the researchers for sustainable agriculture crop production. Abdel-Aziz et al. [59] gave the exogenous foliar application of chitosan NPs laden with NPK (nitrogen, phosphorus and potassium) fertilizers to the wheat plant grown in sandy soil resulted in elevation in yield index variables (harvest index, crop index and mobilization index). Ajirloo et al. [60] reviled the potential role of nanofertilizers for instance, K Nano-Fertilizer and N Bio-Fertilizer in improving the yield components of tomato. Analogous study was also reported in red bean (*Phaseolus vulgaris* L.) [61]. Davarpanah et al. [62] demonstrated his findings by giving the exogenous foliar application of zinc and boron nanofertilizers to the pomegranate (*Punica granatum* cv. Ardestani), their application increased the yield and quality of pomegranate fruit and

also improved the tree nutrient availability. Recent study advocated that apatite NPs could be used as a phosphorus (P) fertilizer that sustained P availability as required by the plant [63,64]. Nanotechnology now replacing the traditional food in agri-food industry by launching nano-manufactured products, for instance, Canola Active Oil, a cooking oil enclosing designed “nanodrops” (Shemen Industries, Tel Aviv, Israel) [65], Nanotea (Tea) (Qinhuangdao Taiji Ring Nano-Products Co., Ltd., Hebei, People’s Republic of China), Nanoceuticals Slim Shake Chocolate that contains cocoa-infused “Nano Clusters” which does not requires extra sugar [2].

Conclusion

In the present era, world’s 7 billion populations [66] have undergone to face the tremendous challenges in multiple platforms, especially in the field related to food and agriculture. Food is the primary requirement for the survival of population. Therefore, food requirement entails a huge pressure on the agricultural sectors for their demand [67]. However, there is a dire need to evolve and incorporate such technique that could maintain sustainable agricultural crop production. Thus, nanotechnology has become an efficient field for research in agricultural production [2]. Nations Millennium Development Goals (MDG’s) have set goals for meeting the needs of millions of people who are facing lack of access basic human needs such as, safe drinking water, energy source, health and education. Therefore, nanotechnology could become boon for the welfare of mankind by achieving the MDG’s, but with a watchfulness over the possible risks of nanotechnology for developing countries [68-70]. In case of nanotechnology the arrival of manufactured nanomaterials fetches multiple threats related to agri-food industry. But it does not means that the use of ENPs could only bring risk, therefore there is a plenty of scientific studies are reported in support of the novel application of nanoparticles in the field of agriculture productivity. Because of their unique feature like size, shape, density, surface reactivity and their targeting potential researchers are using nanomaterials of different ranges through various applications, with the rise of research on using nanoscale materials (carbon NPs, metal NPs, metal oxide NPs) they become helpful for the crop management, for attaining the nutrient requirement, enhancing microbial activities, suppressing the disease availability, increasing nutrient availability to the plant and also elevating the crop yield and productivity [71]. Nowadays nanoparticles like metal and metal oxide nanoparticles, carbon based nanotubes such as carbon quantum dots, graphene quantum dots, graphene oxide, and single and multi-walled carbon nanotubes are manipulated in such a way as it can be used to improve crop yield and also alleviating toxicity in the form of nanofertilizers, nanopesticides, nanoherbicides, insecticides and food additives and food manufacturing. Therefore, nanotechnology has remarkable potential and application for bringing sustainable agriculture.

Future Prospects

Several studies on nanoparticles-plant interaction have already been made. However, a large number of studies are still required to enhance the plant growth with least adverse outcome. In spite of nano incorporated positive implications on agriculture, risk assessment should also be taken into consideration to maintain long term agricultural sustainability. Therefore, the focus should made on the diverse application of nanoparticles in area related to agriculture, such as plant growth and development including availability of soil microorganism, macro and micro- nutrient availability, mitigation of different abiotic stress and the possibilities of using nanomaterials for

sustaining the agriculture production that allows risk free environment in the near future. Thus, the current trends of Engineered Nanoparticles (ENPs) research demonstrated the potential landmark in sustainable agricultural through the improvement of quality food production with minimizing its adverse impact on human health as well as environment. On the other hand its concentration dependent behavior with living system is a major threat that must be analyze before its wide application to avoid its harmful impact.

Conflict of Interest

Authors declare that they have no conflict of interest.

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