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Nanofertilizer and its application in horticulture

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Abstract

Current horticultural practices are being upgraded and updated by use of various technologies including nanotechnology. Use of nanotechnology for developing nanofertilizers could improve the nutrient use efficiencies, reduce nutrient loss, replenish soil fertility, increase crop yield, maintain ecosystem, soil health and curtail serious soil problems. Nano-fertilizers are formulated to deliver and emit nutrient tardily and deliberately. Regular release of nutrients by nanofertilizers help in augmenting nutrient use efficiency beyond several related adverse outcome. Nanofertilizers may increase the fruit yield and quality of various horticultural crops which will inturn increase the nutritive content of products as well as increase the global food security. The present review discuses different aspects of nanofertilizer application in horticulture.

Key words: Nanofertilizers, chitosan, chlorophyll, nanozeolite, proliferation, food security

Introduction

With increasing world population, present Agriculture production must be increased by 70 % to feed the world population by 2050 which will increase by 110 %. To achieve global food security, increased food production and food productivity, it is necessary to ratify innovative and futuristic advances and technologies in improving cultivation, yield and productivity of horticultural crops. Nanotechnology can be used in production, manufacturing of processed products, storing, packaging and transportation of horticultural produce (Mousavi and Rezai, 2011; Ditta, 2015). Energy, the economy, environment, long-term incorporation by soil microorganisms and fertilizer products can be enhanced significantly by use of nanotechnology (Derosa *et al.*, 2010).

Problems of imbalanced fertilization, nutrient deficiencies, low fertilizer use efficiency and decline of organic matter in soil must be addressed to feed increasing world population. For which nanobased fertilizer formulation with multiple functions must be evolved. To improve soil fertility and increase crop productivity huge amounts of fertilizer is required (Li *et al.,* 2014; Dubey and Mailapalli, 2016). Use of chemical fertilizer is required to replenish world's soil fertility which is seriously degraded to approximately 40 % due to intensive farming practices (Dijk and Meijerinck, 2014). Apart from efficiency of other agriculture input, fertilizers contribute one third of agriculture and horticulture productivity. However, performance of traditional fertilizer barely exceeds 30-40 %. Performance of traditional fertilizers remained constant for the past decades, for nitrogen (N) 30-35 %, phosphorus (P) 18-20 %, and potassium (K) 35-40 % (Subramanian *et al.,* 2015). Uptake of nutrients can be increased by encapsulating fertilizers in nanoparticles. Nanofertilizers can be the best alternative to overcome chronic problems of eutrophication and enhanced nutrient use efficiency to reduce macro and micro nutrient deficiency (Shukla *et al.,* 2019). Potential use of nanofertlizers in agriculture has widely been reviewed (Naderi and Shahraki, 2013; Liu and Lal, 2015; Chhipa, 2017; Jyothi and Hebsur, 2017; Raliya *et al.*, 2018), however, current paper enumerates the categorical information on use of nanofertilizers in different horticulture crops which have immense importance for harnessing the technology into crop cultivation and increasing production of horticultural crops.

Nanofertilizers: Nanofertilizers are nutrient carriers developed using substrates with 1-100 nm nanodimensions of that can supply single nutrient or in combination to enhance plant growth, performance and yield. Though they do not directly provide nutrients to crops still they have better performance when compared to conventional fertilizers. Nanofertilizer is any product synthesized with nanoparticles or nanotechnology by enriching nutrients to the adsorbents to enhance performance of nutrients and improve plant nutrition compared to traditional fertilizers. Extensive surface area of nanoparticles accomplish them to hold nutrients abundantly and release nutrients deliberately to meet the requirements of crop without any adverse outcome. Nanoporous materials or nanotubes can be exploited for encapsulating nanofertilizers by coating with lean defensive polymer film derived as emulsion or particles of nanoscale dimension (Chippa, 2017).

Nutrient release rate in nanofertilizers can be controlled as per environmental conditions like soil moisture percentage, temperature fluctuations and soil acidity level to effectively increase the efficiency of nutrients for plant growth compared to conventional fertilizers. Nano-fertilizers are formulated to deliver and emit nutrient for more than 35 days deliberately and regularly. This may help in decreasing adverse effect on soil, plant and environment by enhancing the efficiency of applied nutrient and subsequently decrease leaching loss of nutrients (Siddiqui *et al.,* 2015). Preference of nanofertilizer is higher compared to traditional fertilizers as they are more efficient and can be absorbed easily by both roots and shoots due to slow and controlled release of fertilizers. Therefore, nanofertilizers are more effective and efficient in absorption capacity compared to traditional fertilizers (Solanki *et al.,* 2015; Belal and El-Ramady, 2018; Khan and Rizvi, 2017).

Three classes of nanofertilizers- Nanoscale fertilizer, Nanoscale additives and Nanoscale coating have been proposed. To retard nutrient solubility for slow release of nutrients Nanomaterial coatings such as a nanomembrane may be employed. Use of nanotechnology is already adopted for medical and engineering applications however use of nanotechnology for fertilizers is still in its initial stage. Several potential nanofertilizer designs have been adapted from Manjunatha *et al.* (2016) as Slow release, Quick release, Specific release, Moisture release, Heat release, pH release, Ultrasound release and Magnetic release. Wang *et al.* (2013) and Barrios *et al.* (2017) studied effect of nanoparticles on nutritional quality of tomato and Zhao *et al.* (2014) studied the same effect on cucumber. From their observations we can conclude that nanofertilizers have positive effects on nutritional quality of crop plants as well as growth of crop plants. Nanofertilizer use may increase fertilizer use efficiency and minimize leaching loss of nutrients like nitrogen. Due to controlled release of nanofertilizer, negative impacts and other side effects will be minimized.

Cui *et al.* (2010) summarized advantages of nanofertilizers in comparison to conventional fertilizers as: The smaller size of nanofertilizers nutrients increase solubility of nutrients with better dispersion in soil compared to large particle size in conventional fertilizers. Nanofertilizer reduce soil adsorption, fixation and increase bioavailability while conventional fertilizers have less bioavailabilty to plants. In nanofertilizers, fertilizer use efficiency is higher and uptake ratio of soil nutrients in crop production is higher compared to less efficiency of bulky conventional fertilizers. In nanofertilizers encapsulation allows steady release of water soluble nutrients whereas in conventional fertilizers there may be toxicity due to release of excessive fertilizers at one go, this may damage ecological balance. Nanofertilizers can extend duration of nutrient supply of fertilizer released to the soil whereas in conventional fertilizers the nutrients are released at once, at the time of delivery are used up by the plants and rest of the nutrients are transformed into dissolved alkali in the soil. In nanofertilizer loss of nutrients by leaching is depreciated however there is high loss of nutrients by leaching, rains and drift in conventional fertilizers.

Macronutrient nanofertilizers: Macronutrient nanofertilizer include nitrogen, phosphorus, potash, calcium, magnesium and sulphur. They are required by plants in comparatively huge amount. The global demand of macronutrient fertilizers is estimated to increase to 263Mt by 2050 (Chhipa, 2017; Alexandratos and Bruinsma 2012). Nutrient use efficiency is higher in nanofertilizer due to extensive surface area correlated to traditional fertilizers. Kottegoda *et al.* (2011), Chhipa, (2017) and Kottegoda *et al.* (2017) found that nano-urea coated zeolite chips and urea modified hydroxyapatite can be used for controlling the release of nitrogen macronutrient. The efficacy of nano urea modified hydroxyapatite encapsulated under pressure into *Gliricidia sepium* was demonstrated by Kottegoda *et al.* (2011). The release pattern was observed and nitrogen was released slowly over 60 days, which proves that the slow release will effectively enhance uptake of nitrogen by plants. Therefore, yield of plants could be significantly increased compared to traditional fertilizer (Kottegoda *et al.,* 2011). This study demonstrates that macronutrient formulation of nanofertilizer can be promising for increasing crop yields. Apart from the above, several nano particles have been used for nitrogen macronutrient source and are capable of slow and controlled release of nitrogen over long periods, they are urea modified zeolites, mesoporous silica and hydroxyapatite nano particles (Liu and Lal, 2015; Monreal *et al.,* 2016). Development or creation of nano macronutrient with high efficiency *i.e.* low leaching rate, low immobililization rate by soil and high plant uptake rate and low environmental risk *i.e.* low eutrophication potential and low nitrogen leaching rate is required.

Micronutrient nanofertilizers: Micronutrient fertilizers include iron, manganese, zinc, copper, molybdenum and other nutrients. They are required by plants in relatively smaller amounts. Though only a trace amount is required they are required for proper crop growth. Dimkpa and Bindraban (2017) mentioned that for enhancing crop growth, development, proper metabolism and increasing nutritive content in crops nanoscale micronutrient forms can be used. Micronutrients as soluble salts are often added to macro nutrient fertilizers like nitrogen, phosphorus and potash at low rates *i.e.,* 5 mg/L for crop uptake. There is widespread micronutrient deficiency prevailing in Asian countries due to calcareous soils. High soil pH, severe drought, absence of organic matter, salt stress, imbalanced application of NPK fertilizers also leads to calcareous nature of soils in Asia. This leads to severe deficiency of micronutrient and induce several stress related disorder in plants which significantly decrease crop yield and simultaneously increase spread of various pest and diseases and low fertilizer use efficiency (Malakouti, 2008). However, in alkaline soil, coarse soil or soil with low organic matter, availability of the applied micronutrients may become low and micronutrient deficiency may occur (Fageria *et al.,* 2010). Excessive use of chemical fertilizers decreases the amount of these micronutrients present in soil. As a remedy nanoformulations of micronutrients can be applied to soil or sprayed on plants to enhance soil health and vigour. Deficiency of zinc, an essential micronutrient for plant growth, is commonly observed in soil. Mortvedt (1992) states that to correct deficiency of zinc in soils zinc oxides (ZnO) and zinc sulphates can be used. Zinc oxide nanoparticles can be combined with complex fertilizers to increase the efficiency of recommended dose of fertilizers (Kale *et al.,* 2016). Nano micronutrient having control on Molybdenum field leaching and soil fixation issues for Fe, Zn or Cu must be formulated.

Chitosan based nanofertilizer: Chitosan is a linear polysaccharide, which occurs naturally and can also be produced commercially. It is cheap and biodegradable (Malerba and Cerana, 2016). The delivery potential of chitosan in plants and its effect on growth enhancement, antimicrobial, and agrochemical (micronutrient and pesticide) is being studied widely in horticulture (Malerba and Cerana, 2016; Kumaraswamy *et al.,* 2018). However, due to its insolubility in aqueous media, its efficacy decreases when applied to plants (Malerba and Cerana, 2016). To increase the efficiency and distribution to plants surfaces acidic aqueous media is used for preparation and subsequently dissociated for removal of acids and salts, but this unexpectedly become toxic to target organisms and increase the inhibitory potential of bulk chitosan against microbes (Kumaraswamy *et al.,* 2018). Coating of

NPK fertilizers with chitosan particles is one of the various formulations of nano fertilizers. Biodegradable property, bio- adsorbable and bactericidal property of chitosan polymer can be exploited for nanofertilizer development (Coma *et al.,* 2002). Chitosan nms (cnms) have immense positive surface charge. Solubility of chitosan nanomaterials is high in aqueous media. Studies showed that chitosan nanomaterials can increase crop yield, improve germination of seeds, enhance growth and development of plant, augment uptake of nutrients and boost rate of photosynthesis (Kashyap *et al.,* 2015; Kumaraswamy *et al.,* 2018). Wang *et al.* (2013) demonstrated that chitosan NPK nutrient nanoparticles when applied to plants entered stomata via gas uptake. Mineral salts and nutrients including photosynthetic products required for normal plant growths are translocated by the phloem. Growth of *B. cinerea* in *in vitro* and *in vivo* assays could be directly inhibited by chitosans of various molecular weight. Molecular weight and concentration of chitosans have a great impact on its antifungal properties and effects. Chitosans can be utilized as a substitute for synthetic fungicide for fruits and vegetables. Chitosan, a natural compound enhanced resistance against gray mould caused by *B. cineria* on tomato fruit (Badawy and Rabea, 2009). Chitosan based nanomaterials can be used as growth enhancers in plants as they have potentiality of exhibiting nanofertilizer characters. Sathiyabama and Charles (2015) exposed tomato foliage to polymer chitosan nanomaterials synthesized from fungal cell wall and observed that the treatment increased production of flowers and fruit yield. Root application of copper chitosan PVA nanomaterials to tomato plants at a concentration of 0.02/kg exhibited 10 % increase in antioxidant capacity and lycopene content, diameter of stem increase by 13 %, dry mass increase by 30 % and yield increase by 17 % when compared to control (Hernandez *et al.,* 2017). Root application of Cu-chitosan nanomaterial at 0.06 mg/L dosage in tomato improved plant growth upto 29 %, increased yield by 30 % and fruit lycopene content increased by 12 % (Juarez-Malnado *et al.,* 2016).

Plant nano-nutrition: Plant nano-nutrition includes the use of nanoparticles- ZnO, SiO_2, iron oxide, CuO, Mn oxide, nanofertilizers- phosphorus, nitrogen or nanonutrient for providing essential nutrients to plants for growth, development and productivity. Nutrient source for the plant is through nanonutrients or nanofertilizers applied. The nutrients are released deliberately in a regulated manner to meet the crop requirements for better nutrient use efficiency (Kah, 2015; Mastronardi *et al.,* 2015; Subramanian *et al.,* 2015). Though traditional and complexed fertilizers play an important role in sustaining the horticulture productivity however, global use of nanofertilizer in an extensive extent is still meager (Subramanian *et al.,* 2015). Chlorophyll content of black-eyed pea *Pisum sativum* leaf increased when exposed to 250-500 mg/L of iron oxide nanofertilizers (Delfani *et al.,* 2014).

Apart from plant nano-nutrition several engineered nanomaterial exhibit nanofertilizer potential. Gui *et al.* (2017) applied CeO_2 nanomaterials on radish roots at a concentration between 10-100 mg/kg and found that chlorophyll content increased to 12.5 %, fresh biomass increased 2 folds and antioxidant activity was enhanced when compared to controlled untreated plants. Cu Kinetin nanomaterial at a concentration of 50 mg/kg and 100 mg/kg was applied to roots of kidney beans to study its physiological and biochemical effects. It was observed that there was 140 and 30 % increase in pod biomass when Cu-Kinetin alone was used compared to untreated plants (Apodaca *et al.,* 2017). Foliar application of TiO_2 Activated carbon composite SiO_2 nanomaterial at a concentration of 15-120 mg/L in cucumber improved the growth and development of plants by increasing the size of leaf, height, fruit number, yield and total biomass. 60 mg/L concentration proved to be more significant (Yassen *et al.,* 2017).

Application of nanofertilizer in horticultural crops

Vegetables: Productivity of potato *cv.* Arizona, fertilizer use efficiency and agronomic use efficiency could be increased by fertigation with nano NPK fertilizers (Hayyawi *et al.,* 2019). Tomato (*Lycopersicon esculentum*) yielded highest number of fruits per plant, fruit weight, fruit diameter by application of 300 kg/ha K nanofertilizer, and the highest plant height and stem diameter was observed under application of 400 kg/ha K nanofertilizer (Ajirloo *et al.,* 2015). Applicaton of Ferbanat nanotechnology liquid fertilizers @ 3 L/ha to cucumber crop gave highest fruit diameter (Melek *et al.,* 2014). Application of Nanonat @ 3.0 L/ ha to Cucumber crop gives highest TSS (Melek Ekinci *et al.*, 2014). Jackiene *et al.* (2015) applied bio organic nanofertilizers prepared from cattle manure at a dose of 0.5 or 1 litre/ha at beginning of intensive sugar beet development (BBCH 18 and BBCH 37-38) singly or doubly. It was obserbved that all treatments improved photosynthesis process and productivity of sugarbeet. Compared to control plants 1 L/ha dose increased leaves number by 19.6 %, leaf area by 13.4 %, diameter of root by 11.1 %, canopy dry mass by 29.1 %, root biomass by 42.6 %, net photosynthetic productivity by 15.8 %, root yield by 12.6 %, sucrose content by 1.03 % and white sugar yield increased by 19.2 %. Nor *et al.* (2017) studied the effect of nanofertilizer NPK 20:20:20 at 4, 8, 12 kg/ha and commercial single fertilizer NPK 34:56:56 kg/ha as soil application on dwarfed long bean. All the treatments showed increase in chlorophyll content and number of leaves. Nanofertilizers at 8 kg/ha showed best result. Nor *et al.* (2018) studied the impact of nanofertilizer NPK 20:20:20 @4, 8 and12 kg/ha and single NPK 34:56:56 kg/ha on dwarfed long bean. It was observed that all the treatments showed significant increase in growth, height and stem diameter in the treated plants. Drumstick (*Moringa oleifera*) was treated with nano chelated iron at 0, 1, 2, 3 and 4 mg/L, GA_3 at 0, 200 and 400 mg/L and organic fertilizer Acadian at 0 and 1 mg/L. Nanofertilizer and GA_3 at lower concentration showed positive response on the production of α-tocopherols, stigmasterols and campesterol (Kadim, 2018). Iron 2 mg/L, nano iron 2, 4 and 6 mg/L and control treatments were given as foliar spray to Faba bean (*Vicia faba* L.) at three times interval *i.e.* vegetative stage, before flowering and at flowering stage. It was observed that protein percent, chlorophyll content and grain yield increased with increasing nano iron concentration. Nano iron with 6 mg/L spray gave highest grain yield (Nadi *et al.,* 2013). Red bean (*Phaseolus vulgaris* L.) treated with N bio fertilizers showed increase in yield and yield components. It was also observed that K- chelate nanofertilizers could replace chemical fertilizers (Farina and Ghorbani, 2014). Ladan Moghadam *et al.* (2012 investigated on the effect of nano iron chelate on growth and yield of 2 Spinach variety Varamin 88 and Viroflay. The research findings shows that iron chelate nanofertilizers improved wet weight by 58 and 47 % maximum leaf area index. It shows that nanofertilizer has a positive effect on all stages of plant growth and development. *Cucurbita pepo* L. *cv.* White Bush marrow when treated with nano SiO_2 had increased growth and germination of plant, enhanced photosynthetic activity, reduced degradation, improved water use efficiency thereby improved plant defense mechanism of plant and stress (Siddiqui, 2014). Wang *et al.* (2011) experimented on effects of nano-preparation on growth and nitrogen fertilizer use efficiency in cabbage. It was observed that addition of nano-hydroquinone and nano-theophenols in nitrogen fertilizer improved absorption of N, P, K and production of chlorophyll in cabbage. There was increase in N fertilizer use efficiency and production of cabbage by 134.1 and 44.3 %, respectively. This proves that nano preparation improves fertilizer use efficiency and boost crop yields. Carbon nanotubes NPK and chitosan nanoparticles NPK fertilizer applied as foliar spray on french bean plant proved beneficial at low dose. It improved the uptake and absorption of nutrients and enhance their overall growth and development (Hasaneen *et al.,* 2016). Foliar organic nano NPK fertilization in Bhindi at 0.4 % recorded higher nutrient status on post harvest soil (Nibin *et al.,* 2019).

Spices, medicinal and aromatic plants: Sweet basil (*Ocimum basilicum* L) when treated with Fe_3O_4 nanoparticles showed enhanced plant growth, iron and oil content (Elfeky *et al.,* 2013). Nanofertilizers Fe, P, K and control treatments were applied to saffron (*Crocus sativus*) ecotypes. All nanofertilizer treatments had positive affects on saffron flowering and improved yield, however other factors like maternal corm weight and choice of saffron ecotypes also effect saffron production (Amirnia, 2014). Peppermint (*Mentha piperta* L.) treated with nanofertilizer of iron, zinc and potassium gave highest plant height, number and branches of leaves in peppermint (Hassani, 2015). German chamomile (*Matricaria chamomilla* L.) treatment with synthetic nanozeolite/ nanohydroxyapatite as phosphorus fertilizer increased the yield of chamomile and decreased eutrophication risk (Mikhak *et al.,* 2017). Fe nanofertilizer and irrigation application on dill (*Anethum graveolens* L.) shows positive response on seed yield, oil yield percentage and morphological traits. Maximum yield and essential oil percentage can be obtained at 7 days interval proving that they can replace conventional fertilizers for sustainable agriculture (Gholinezhad, 2017). Foliar fertilization of black cumin (*Nigella sativa* L.) nanofertilizer at 0, 1 mL/L and humic acid at 0, 1, 3, 6 mL/L at 3 growth stages proves significant, their combination increased oil content and yield. Humic acid treatment at 3 and 6 mL/L gave highest yield. Nanofertilizer increased the yield and yield components of black cumin (Azizi and Safaei, 2017).

Flowers: Calcium nano-fertilizer had a significant effect on vase life and flower quality of gerbera (Mohammadbagheri and Naderi, 2017). Kaviani *et al.* (2016) applied iron chelate fertilizers at 0, 0.9, 1.8, 3.6 and 4.5 mg/L and Cycocel at 0, 500, 1000, 1500 and 3000 mg/L to poinsettia (*Euphorbia pulcherrima)* plants propagated by stem cuttings. Combination of 1.8 mg/L Iron chelate nanofertilizer with or without Cycocel 1000 mg/L expressed shortest height, more number of leaves, shoots, root length and volume including number of permanent coloured bracts.

Fruits: Application of nutrients and injection of nano NPK fertilizers improved vegetative growth and increased yield of date palm (Jubeir *et al.*, 2019). Foliar spray of nanofertilizers, nano-Zn and nano-B on pomegranate (cultivar Ardestani) led to increase in pomegranate fruit yield, fruit quality, including T.S.S., maturity index, juice and deceases in total acidity (Davarpanah *et al.,* 2016). Fruit cracking and fruit yield in pomegranate (*Punica granatum cv. Ardestani)* was reduced by foliar Ca nano fertilization **(**Davarpanah *et al.,* 2017). Spraying mango trees (Ewasy and Zebda) with nano-zinc at 1 mg/L before flowering improved yield and fruit quality as well as raised resistance of malformation (Zakzouk, 2017). Hence, nanotechnology has a high potential to play a good role in production of horticulture crops, especially in developing countries (Barua and Dutta, 2009). Roshdy and Refai (2016) studied the effect of nano NPK fertilization and conventional fertilizers on date palm cultivar Zaghloul. The result showed that the growth rate, yield and quality of treated dates increase with lower dose of nano NPK fertilization. Olive seedlings *cv.* Kalamat when sprayed with nano NPK gave promising results on growth and performance (Hagag *et al.,* 2018a). Hagag *et al.* (2018b) treated olive seedlings *cv.,* Aggizi with nanofertilizers at 0.02 % during June, July and August by replacing half dose of recommended mineral fertilizer by giving 0.5 %/seedling as soil application. The treatment showed enhanced plant vegetative growth without nutrient deficiency symptoms, and concluded that nano NPK can be alternative to conventional fertilizers and can be promising for the future. Avestan *et al.* (2018) studied the effects of different levels of enriched chelated iron fertilizer at 25, 50, 100 and 200 μ mg/L and common iron on *in vitro* apple ex plants cultivar Gala cultured in MS media. Maximum proliferation was observed in 100 mg/L of enriched nano chelated iron wherein the growth of shoots, leaves and nodes increased showing that it can be used for increasing plant growth. Sabir *et al.* (2014) treated grapevines with sea weed extract (*Ascophyllum nodosum*) and nanosized pulverization over 2 years to study the growth, yield and quality. It was observed that Ca nanobased fertilizers increased foliage development and chlorophyll content in vines. The study revealed that there was improvement in berry quality, growth and yield of vines including nutrient content. Apple cultivars Red Delicious, Golden Delicious and Starking Delicious potted plants were given nano biofertilizer at 0, 1, 2 and 3 g/pot and later examined for their response. 1 g/pot dosage had greater impact on growth of apple plants. The result showed that all application significantly increased height of plant, diameter of stem, leaf area and chlorophyll (Mohasedat *et al.,* 2018). Treatment of Bitter almond seeds with nanofertilizers improved seed germination by 50 % at younger stages compared to chemical fertilizer treatment (Badran and Savin*,* 2018). Flame seedless grapevines were treated with 6 nanofertilizers- concentration of 0.1 or 0.2 % Amino minerals; Orgland, Active-Fe, Boron-10, Amino-Zn and Super Fe, foliar fertilization was given during 3 growing stages. It was observed that best yield, improved berry colouration and highest quality fruits were obtained when the vine was treated with amino mineral nanofertilizer at 0.1 % (Wassel *et al.,* 2017).

Limitations of nanofertilizers: Nanofertilizer researches pave way for sustainable agriculture and horticulture farming system manifesting numerous benefits in production of quality and high yielding crops. However, potential uptake of nanoparticles, its biotransformation and translocation pathways as nanofertilizers in plants studied by Rico *et al.* (2011) showed several positive and negative effects. Nanofertilizers have constraints concerning research gaps; inadequacy of recognised formulation and standardization of products, lack of meticulous monitoring and risk associated management hinders the development and adoption of nanoparticles as nanofertilizers (Remedios *et al.*, 2012; Iqbal, 2019). Deliberate introduction of nanoparticles like nanofertilizers in agricultural activities could result in many unintentional irrevocable outcomes (Kah, 2015). Phytotoxicity of nanomaterial is an imperative issue as dissimilar plant respond differently to various doses of nanomaterials (Ashkavand *et al.,* 2018). Dimpka *et al.* (2013) reported negative impact of silver nanoparticles on wheat plant resulting in disruption of plants growth. Root elongation in cucumber, soyabean, cabbage, corn and carrot is inhibited due to phytotoxicity of uncoated nano Al_2O_3 particles (Yang and Watts, 2005). Accumulation of Ag nanoparticles in roots and shoots of pea seedlings (*Pisium sativum*) leads to declined growth, photosynthetic pigments and chlorophyll content (Tripathi *et al.,* 2017). Cultivation of cucumber (*Cucumis sativus*) in hydroponic media with nano and bulk- iron oxide (Fe_3O_4) at 2000 mg/L over a period of 21 days caused phytotoxicity in terms of biomass and antioxidant enzymes activity (Konate *et al.,* 2018). Zhang *et al.* (2017) observed toxicity symptoms in romaine lettuce when treated at high concentration of nano and bulk iron oxide at 1000 and 2000 mg/kg which diminish chlorophyll content and hinders biomass production. Study on uptake, translocation and accumulation of phytotoxic effect of nanoparticles on carrot shows that nanomaterial ZnO, CuO or CeO_2 accumulate on the outer periderm layer of root. Nanoparticles accumulation may vary depending on the plant species, application time, dosage and types of nanoparticles. This result gave insight to accumulation of nanoparticles in root vegetables which may be translocated to human through dietary consumptions (Ebbs *et al.,* 2016). Nanomaterial accumulation in roots and leaves of plants may not be a feasible option for crop harvest due to health implications (Feregrino *et al.,* 2018). Nanomaterials interact with soil microorganisms and alter nutrient absorption in plants. As nanomaterials can enter plant roots and leaves they have ability to modify the functioning at intracellular levels (Singh, 2017). Mycorrhizal colonization in *Helianthus annuus* decreased due to Ag nanoparticles (Dubchak *et al.,* 2010). In sandy loam soil, soil bacterial groups were negatively affected by nano-CuO and magnetite (Frenk *et al.,* 2013). Owing to their minute size and enhanced surface area nanomaterials are highly reactive and can enter into biological systems with ease. Monodispersity, different size and surface chemistry of nanomaterials can also lead to vivid chemical and physical changes in nanomaterials (Konate *et al.,* 2018). Research shows that nanoparticles may cross cell membrane easily and can be inhaled by farmworkers while spraying, which can reach blood and may reach brain, liver and heart (Suppan, 2017). Regulatory mechanism of enzymes and other proteins might be affected by these nanoparticles (Bhushan, 2007). Research shows that carbon nanomaterials may modulate gene expression in plants by changing cell division pattern and plant development. They also cause suppression of seedling growth and root growth as the small sized nanoparticles can penetrate through seed coats and can be translocated to various plant parts (Nair, 2018). Though there are several negative impacts reported on nanofertilizers the findings are still meagre to conclude that nanofertilizers have negative impact. In depth study regarding human health risk, food safety, life cycle of nanofertilizers, standardization of formulations for several crops and regulations must be carried out systematically to assess the possible positive and negative effects on all associated risk.

To achieve global food security and to increase food production and food productivity, initiatives must be taken to improve technologies in cultivation and production of horticultural crops. Nanotechnology has the potential to revolutionize horticultural systems particularly where the issues of fertilizer applications are concerned. The nanomaterials can be efficiently applied through soil and foliage. At higher concentrations they can be harmful for the plants however at lower concentrations nanofertilizers have positive effects on nutrient delivery by improving overall plant growth and development including yield. Though several negative effects are reported, they are also proved to be beneficial. Nanofertilizers must be optimised in order to create stable standardized formulations targeted to meet different foliar and soil requirements of particular crops. Nanotechnology must be utilized by developing nanofertilizers to increase horticulture productivity, improve food security, increase plant resistance to climatic change and stress, increase plant defense mechanism, enhanced plant growth and yield with superior quality traits. Nanofertilizers can be used to reduce leaching loss of nitrogen, prevent soil health and helps in long term improvement of soil microorganism activities and overall it has profound impact on conserving energy and helps in improving the economy. However, proper legislation and limits must be framed in order to prevent soil health and soil microbial activities. Nanomaterials must be developed for marketing to replace bulky conventional fertilisers. Micronutrient deficiency and macronutrient deficiency issues can be addressed using macronutrient nanofertilizers, micronutrient nanofertilizers, and chitosan-based nanofertilizers. Plant nanonutrition and use of various nanomaterials with fertiliser potential have been shown to increase multi-crop yields.

Though, the use of nanofertilizer has positive effects, its introduction may be accompanied with several risk factors which is still indefinable. Nanofertilizers with standardised stable formulation for several crops must be developed with aim to prevent toxicity and safety. Awareness and researches including in depth studies on various horticultural crops must be carried out to study related risk and impact on human health for better acceptance among the public or societies.

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