Chapter 19
Applications of Nanobiotechnology to Mitigate Mineral Nutrients Deficiency Stress in Crop Plants

Saima Amjad and Mohammad Serajuddin

Abstract Environmental challenges adversely affect plant growth and their productivity worldwide. Therefore, there is a need for the adoption of new technologies. The rapid potential development in nanotechnology influences the agriculture and food industry, which sustainably increases crop productivity by using new techniques, i.e., use of nanofertilizers and nanopesticides for better nutrient efficiency and pest management. Nanofertilizers are an excellent fertilizer that improves nutrient use efficiency of plants by slow and specific release of nutrient minerals and replacing the overuse of conventional fertilizers. Previous studies on nanoform of mineral particles such as calcium carbonate, cerium oxide, molybdenum, zinc, titanium dioxide, manganese hollow core shell and magnesium nanoparticles showed that they enhanced the nutrient uptake in plants and it also reduces metal accumulation in crop plants. It improved new set of devices to develop a genetically based tool using nanocapsules, nanofibers and nanoparticles. Hence, based on the research data available so far, the present chapter provides an overview on the various nanoform of mineral nutrients, which are beneficial for crop productivity. Moreover, this chapter also focuses on challenges and function of nanoparticles so as to understand the mode of action of nanoparticles on plants to overcome the plant nutrient stress.

Keywords Agriculture · Nanobiotechnology · Nanoparticles · Nutrient deficiency · Nutrient stress

19.1 Introduction

Plant nutrition deficiency is an important limiting aspect for plant growth and productivity after drought and salinity (Rajemahadik et al. 2018). The plant requires nutrients for their growth and development and absorbs most mineral nutrients present in the soil through their roots. However, to compensate the deficiency of nutrients, fertilizers

S. Amjad · M. Serajuddin (✉)
Department of Zoology, University of Lucknow, Lucknow, UP 226007, India
e-mail: serajuddin_m@lkouniv.ac.in

J. M. Al-Khayri et al. (eds.), *Nanobiotechnology*,
https://doi.org/10.1007/978-3-030-73606-4_19

are applied to the soil for healthy development of plants (Baloch et al. 2008; Bernal et al. 2007). Plants require seventeen elements for their growth and development out of which 14 are essential nutrients required. Among these essential nutrients, six are macronutrients that required in large amounts viz. calcium (Ca), potassium (K), magnesium (Mg), nitrogen (N), phosphorus (P), and sulfur (S) (Maathuis 2009). The micronutrients viz. chloride (Cl), copper (Cu), manganese (Mn), iron (Fe), zinc (Zn), cobalt (Co), molybdenum (Mo), and nickel (Ni) are required in a small amount (Marschner 2012; Zeng 2014). The nutrition deficiency found in commercially available economic crops influence human health, especially the people that belong to the rural areas, but the sustainable approach of nanotechnology diminishing these challenges.

During past few decades, biotechnological approach used for bioremediation or phytoremediation to restore agro-chemically damaged soils (Ghormade et al. 2011) to raise the use of nutrient efficiency in crops and to inhibit mineral losses. Several research studies revealed that plants grow by adapting a specific mechanism to uptake their required level and acclimate variation of nutrient availability (Ohkama-Ohtsu and Wasaki 2010; Schachtman and Shin 2007). Several strategies have attempted to provide protection and nutrition to the plants. The plant growth was hampered by two causes, the lack of micronutrients or either the pore size of roots is so small that it is unable to uptake and translocate the nutrients inside the plant. Therefore, it is essential to get better nutrient uptake competency strategies to enhance the quality and production of the crop (Elemike et al. 2019). The required necessities of nutrients in plants are provided by the fertilizers, with the certainty that minerals could be absorbed from the soil. The widespread contributions of biotechnology from conventional breeding to improve crop nutrient efficiency have been made through the molecular technique approach, but these achievements are limited (Ashraf et al. 2011). The transporters and enzymes efficiently involve in nutrient absorption and are necessary for acquiring elevated nutrient uptake, and it directly affect the status of crop yield. In an instance, the accumulation of nitrogen in shoot and grains of wheat plants increased by the over-expression of the glutamine synthetase gene (GS1) (Hu et al. 2018), while in maize plants the number of kernels enhanced by the over-expression of GS13 (Martin et al. 2006). The transgenic rice plants required a high amount of nitrogen for growth, OsAMT1 efficiently working as ammonium transporter function in elevating the nutrient uptake efficiency under optimal as well as suboptimal nitrogen conditions (Ranathunge et al. 2014). However, these approaches are inadequate and it is necessary to resolve the limited approach of biotechnology by involving the application of nanotechnology towards agriculture (Ghormade et al. 2011). The main purpose of the application of nanomaterial in agriculture is to overcome nutrient stress, pest control, reduce the effect of hazardous chemicals and crop protection as shown in Fig. 19.1 (Thakur et al. 2018).

The ongoing application of nanobiotechnology provides an opportunity to overcome the mineral nutrient stress in plants. The engineered nanoparticles hold an immense promise in the growing use of nanofertilizers, which utilize competence along with growing agriculture production.

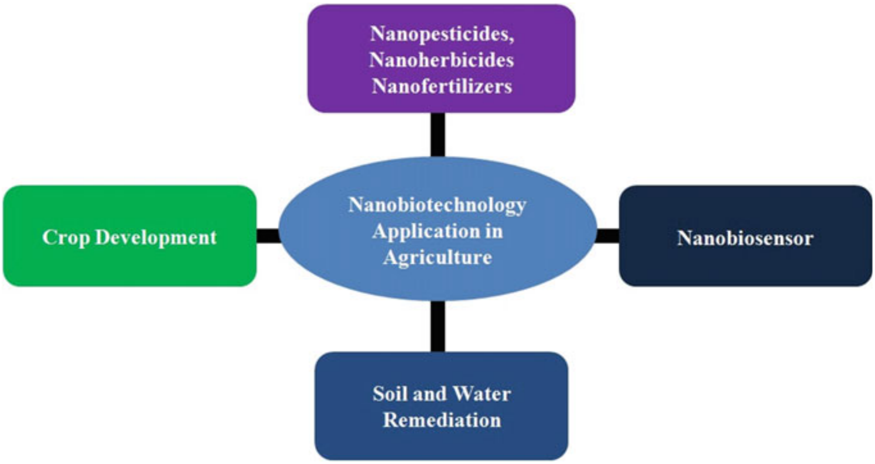

Fig. 19.1 Schematic representation of application of nanobiotechnology in agriculture for better crop productivity (Fig constructed by Saima Amjad)

19.2 Sustainable Approach of Nanobiotechnology in Agriculture

Nanotechnology is the upcoming innovatory technology after biotechnology revolution. It has an extensive application in various disciplines such as electronics, optics, pharmaceuticals, agriculture, and the environment. In the last few decades, it is growing with time and become a significant application in agriculture (Chhipa 2017). Nanotechnology can be used to design, develop and synthesize minerals in nanoform and this application gives considerable assurance for agricultural crop productivity (Baruah and Dutta 2009; Kuzma 2007; Navrotsky 2000). It is the procedure to design, develop and synthesize nanomaterials to represents an area holding considerable assurance for agricultural field in the form of nanofertilizers (Baruah and Dutta 2009; Kuzma 2007; Navrotsky 2000). Nanotechnologies using next generation of pesticides and fertilizers in agriculture by using functionalize nanomaterial and nanoparticle. It also minimizes the loss of pesticides and fertilizers by controlled and targeted delivery through nanocarriers (Ghormade et al. 2011; Joseph and Morrison 2006; Khot et al. 2012; Nair et al. 2010; Robinson and Morrison 2009; Scott and Chen 2013). The plant protection material (nanopesticides) and nutrients (nanofertilizers) have advanced properties because of their unique physical, chemical and rapidly dispersible properties of nanoparticles, which also enhanced the uptake of nutrition in the plant (Ghormade et al. 2011). There are several wide varieties of materials used to synthesize nanoparticles are magnetic materials, metal oxides, semiconductors, quantum dots, lipids, ceramics, polymers (synthetic or natural), emulsions and dendrimers (Puoci et al. 2008). However, the limitation of conventional fertilizers is that it does not contain all the required nutrients for plant augmentation and development. Therefore, it becomes an interesting venture for nanofertilizers that can address nutrient deficiency and environmental issues related with fertilizers (Dimkpa and Bindraban 2017). Sustainable and productive crop management can also be achieved by using an important tool of foliar fertilization in nanotechnology. The present knowledge of the factors, which influence the efficacy of foliar applications, may be determined by the art of nanotechnology (Eichert et al. 2008; Mortvedt 1992; Millán et al. 2008; Pandey et al. 2010; Roco 2011).

Leaching and loss of harmful substances have also reduced by using the encapsulated nanominerals, it plays a vital role in environmental protection (Zheng et al. 2005). The other accomplishment of nanobiotechnology is to develop nano-carriers for smart delivery systems and nanosensors, which are broadly used to assess environmental pollution in soil and water system of the agricultural field. Several sensors already developed on the concept of nano-detection to detect the traces of heavy metals such as electrochemical sensors, optical sensors, biosensors and so on (Handforda et al. 2015; Ion et al. 2010; Parisi et al. 2014). Nanobiotechnology is also being explored to improve crop productivity in plant reproduction through hereditary transfection (Prasad et al. 2014; Torney et al. 2007). It offers a new set of devices to develop a genetically based tool using nanocapsules, nanofibers and nanoparticles (Gutiérrez et al. 2011 and Nair et al. 2010). A Chitosan nanoparticle has versatile properties and emerged as a valuable carrier for genetic transfer of material; it can be modified by PEGylated to control the transfer of genetic material (Kashyap et al. 2015).

19.3 Strategies to Improve Plant Nutrient Uptake by Nanobiotechnology

The nanobiotechnology plays a noteworthy role in the plant production through the controlled release of mineral nutrients (Gruère 2012; Mukhopadhyay 2014). Nanoparticles or nanominerals size lies between 1−100 nm and different from their corresponding parental materials, which produce both useful and harmful biological effects in a living cell (Nel et al. 2006). Fertilizer nanoparticles are also known as magic bullets which enhance crop productivity to deal with global food problems (Bhatt et al. 2020). Several research studies reported the toxicological interaction of engineered nanoparticles on plants even though these studies implicated the exposure of nanoparticles in a certain specific situation with a short period of time at high doses. On the contrary, very few studies paying attention on the favorable impact of nanoparticles on plant development and productivity. Furthermore, a mineral nanoparticle integrated into conventional fertilizers and pesticides to increase the production, also reduces the chance of diseases and improves nutritional augmentation (Elmer and White 2018; Prasad et al. 2017). The potential benefits of nanotechnology can understand by application of some mineral nanoparticles on plants and analyze the mechanism of transport and nutrient uptake. The mechanism of some nanoparticles in nutrient stress has given in Table 19.1 to understand the function of mineral nanoparticles in plants.

Table 19.1 Nanomineral nutrients and their application on different type of crops and their effect on plant growth and physiology

Nutrients	Crop		Function	References
	Botanical name	Common name		
Ca	*Arachis hypogaea* L.	Peanut	Enhanced the nutrient content in shoot and root of plant	Liu et al. (2004)
	Ziziphus mauritiana Lam.	Indian plum	Increased in Ca^{2+} uptake	Hua et al. (2015)
$CaCO_3$	*Arachis hypogaea* L.	Peanut	Enhanced Ca^{2+} uptake and growth	Liu et al. (2005)
nano U-NPK	*Triticum durum* Desf	Durum wheat	Increased efficiency of fertilization, yields of grains, decline lower 40 wt% of N amount	Ramírez-Rodrígu et al. (2020)
CaP	*Zea mays* L.	Maize	Promote plant growth efficiency, enhanced root, and improved vitality properties	Rane et al. (2015)
CeO_2	*Cucumis sativus* L.	Cucumber	Uptake of Mg^{2+} ion, Improved starch and globulin content	Zhao et al. (2014)
Cu	*Lactuca sativa* L.	Lettuce	Amplified the shoot and root length	Shah and Belozerova (2009)
CuO	*Zea mays* L.	Maize	Improved plant growth	Adhikari et al. (2016)
Cu	*Triticum aestivum* L.	Millat-2011 (wheat)	Enhanced growth and yield of chlorophyll content, leaf area, fresh and dry weight, and root dry weight of plant	Hafeez et al. (2015)
	Cajanus cajan L.	Pigeon pea	Enhances plant growth and seedlings of the plant	Shende et al. (2017)
Hydroxyapatite	*Glycine max* (L.) Merr	Soybean	Improved the growth rate and seed yield	Liu and Lal (2014)

(continued)

Table 19.1 (continued)

Nutrients	Crop		Function	References
	Botanical name	Common name		
SPIONs	*Glycine max* (L.) Merr	Soybean	Increased chlorophyll content	Ghafariyan et al. (2013)
	Pisum sativum L.	Pea	Enhanced seed weight and chlorophyll content	Delfani et al. (2014)
Fe_2O_3	*Arachis hypogaea* L.	Peanut	Enhanced root length, biomass, and SPAD	Rui et al. (2016)
FeO	*Medicago falcata* L.	Yellow medick	Increased chlorophyll α fluorescence, plant root length and miR159c expression	Kokina et al. (2020)
Mn	*Vigna radiata* (L.) R. Wilczek	Mung bean	Enhanced the growth of shoot length and chlorophyll content. It also increased the rate of photosynthesis	Pradhan et al. (2013)
	Oryza sativa L.	Rice	Improved Zn uptake in plant	Yuvaraj and Subramanian (2015)
Mg	*Vigna unguiculata* (L.) Walp.	Cowpea	Mg content increased in stem and plasma and it also accelerated the enzyme activity	Delfani et al. (2014)
	Triticum aestivum L.	Common wheat	Increased growth and yield of plant and minerals uptake	Rathore and Tarafdar (2015)
MgO	*Arachis hypogaea* L.	Peanut	Enhanced seed germination, growth rate mechanism and biomass production	Jhansi et al. (2017)
Mo	*Cicer arietinum* L.	Chickpea	Plant mass and nodules number increased	Taran et al. (2014)
			Enhanced root area, diameter, length, perimeter, and tips number, improved microbial activities, increased biomass and grain yield	Thomas et al. (2017)

(continued)

Table 19.1 (continued)

Nutrients	Crop		Function	References
	Botanical name	Common name		
Si	*Ocimum basilicum* L.	Basil	Chlorophyll content increased and reduced proline content	Kalteh et al. (2018)
	Pisum sativum L.	Pea	Reduced the accumulation of Cr in roots and shoots, enhanced antioxidant activity	Tripathi et al. (2015)
	Triticum aestivum L.	Wheat	Improved development, photosynthesis of plant and reduced the oxidative stress, inhibited metal accumulation	Ali et al. (2019)
TiO_2	*Spinacia oleracea* L.	Spinach	Increased plant dry weight	Zheng et al. (2005)
	Spinacia oleracea L.	Spinach	N_2 fixation improvement	
	Vigna radiata (L.) R. Wilczek	Mung bean	Improvement in plant growth and nutrient content	
	Vigna unguiculata (L.) Walp.	Cowpea	Cowpea yield increased up to 26–51%	Owolade and Ogunleti (2008)
	Coriandrum sativum L.	Coriander	Improved nutritional quality, enhanced root and shoot fresh biomass	Hu et al. (2020)
Zn	*Lolium* L.	Ryegrass	Root extension	Lin and Xing (2008)
ZnO	*Vigna radiata* (L.) R. Wilczek and *Cicer arietinum* L.	Mung bean and chickpea	Plant growth increased in mung bean and in chickpea plant	Mahajan et al. (2011)
	Cucumis sativus L.	Cucumber	Increased root dry weight and fruit gluten	

(continued)

Table 19.1 (continued)

Nutrients	Crop		Function	References
	Botanical name	Common name		
	Brassica napus L.	Rapeseed	Root extension	Lin and Xing (2007)
	Arachis hypogaea L.	Peanut	34% enhancement in pod yield for per plant	Prasad et al. (2012)
	Cicer arietinum L.	Chickpea	Increased shoot dry weight and rate of antioxidant activity	Burman et al. (2013)
	Zea Maize L.	Maize	Improved plant length and dry weight	Adhikari et al. (2015)
	Cyamopsis tetragonoloba (L.) Taub.	Lond bean	Enhancement in plant growth and nutrient content	Raliya and Tarafdar (2013)
	Lactuca sativa L.	Lettuce	Stimulated catalase enzyme activity, enhanced seed germination, and biomass	Rawashdeh et al. (2020)

19.3.1 Calcium Nanoparticles

The calcium in the nanoforms was more effective compared to the chelated form; it improves plant growth and production (Liu et al. 2005). Effect of calcium carbonate nanoparticles have studied on *Arachis hypogeae*, L. it showed that the nano form of calcium enhanced branch number and increased 15% weight (fresh and dry) of plants (Liu et al. 2004; Tantawy et al. 2014). Liu et al. (2005) have reported a study that showed improvement in the physiological process for instance chlorophyll content of tomato plant increased by the effect of nano calcium. Biomimetic calcium phosphate nanoparticles with the composition of potassium (K) and nitrogen (N, as nitrate and urea) was used as a multinutrient nanofertilizear (nano U-NPK) for the cultivation of *Triticum durum* Desf. The result showed the application of the slow-release nano U-NPK were a promising strategy towards increasing the competency of the fertilization, and yields of grains were obtained, and the additional advantage of using a much lower N amount (a decline of 40 wt%) (Ramírez-Rodrígu et al. 2020). *Zea mays* L. crop has been treated with calcium phosphate nanoparticles (CaPNPs) along with *Piriformospora indica* and *Glomus mosseaec* which promote plant growth efficiency, root enhancement, and improved vitality properties (Rane et al. 2015).

19.3.2 Cerium Oxide Nanoparticles

Zhao et al. (2014) conducted a study on cucumber (*Cucumis sativus* L.) plants grown in soil treated with Cerium Oxide (CeO_2) nanoparticles. The results indicated that CeO_2NPs influenced the fruit flavor decreased the antioxidant capacity and increased starch and globulin content. It considerably enhanced the uptake of Mg^{2+} ion, which is a vital constituent of the chlorophyll molecule. It also decreased the uptake of molybdenum (Mo) concentration and altered the non-reducing sugars, phenolic content and changed the protein fractionation.

19.3.3 Copper Nanoparticles

Copper (Cu) metal is an important micronutrient required for plants enzymatic activity, which functions as a regulatory co-factor or catalyst for a large number of enzymes or acts as a functional structural. Adhikari et al. (2016) investigated the effect of copper oxide (CuO) nanoparticles (< 50 nm) on the development, bioaccumulation and enzymatic action of maize (*Zea mays* L.) plant. The experimental studies showed the easy assimilation of CuO nanoparticles through plant cells and increase the growth of maize by regulating the different enzyme activities. The glucose-6-phosphate dehydrogenase enzymatic activity was extremely influenced by copper oxide (CuO) nanoparticles and affected the pentose phosphate pathway in maize plants. Hafeez et al. (2015) have studied the effect of the concentration-dependent copper nanoparticles (CuNPs) on Millat-2011 (*Triticum aestivum* L.) crop which significantly enhanced growth and yield of the plant, chlorophyll content, leaf area, fresh and dry weight, and root dry weight. Similarly, the exposure of biogenic CuNPs (20 ppm) on pigeon pea (*Cajanus cajan* L.) plant was evaluated which enhances growth such as height, root length, fresh, and dry weights and seedlings of the plant (Shende et al. 2017).

19.3.4 Hydroxyapatite Nanoparticles

Urea based nitrogen fertilizers viz. Urea-coated zeolite chips and hydroxyapatite has been used in nanoparticle form as a source of nitrogen (N) to study the controlled release of N for a long duration of time (Kottegoda et al. 2011; Millán et al. 2008). Similarly, hydroxyapatite ($Ca_5(PO_4)_3OH$) nanoparticles have a significant impact on seed yield of *Glycine max* (L.) Merr., 20% and 33% increment in seed yield as compared with conventional phosphorus treated plant (Liu and Lal 2014).

19.3.5 Iron Oxide Nanoparticles

Delfani et al. (2014) analyzed the iron nanoparticles (FeNPs) effect on blacked eyed pea plants which not only improved the pods number per plant but also enhanced the weight of seeds and improved the chlorophyll biosynthesis. FeNPs enhanced the seed protein content by 2% compared to Fe. In another study comparative effect of iron oxide nanoparticles (Fe_2O_3NPs) and a chelated-Fe fertilizer (ethylenediaminetetraaceticacid-Fe; EDTA-Fe) were studied on the development and growth of *Arachis hypogaea* L. plant. The obtained results showed Fe_2O_3NPs enhanced root length, biomass, and Soil Plant Analysis Development (SPAD) chlorophyll meter values of peanut (*Arachis hypogaea* L.) plants. It also regulated phytohormone contents and antioxidant enzyme activity which promote plant growth (Rui et al. 2016). Also, in *Glycine max* (L.) Merr. plant chlorophyll content was enhanced by superparamagnetic iron oxide nanoparticles (SPIONs) without any phytotoxicity. Additionally, the physicochemical characteristics of SPIONs had an essential role in sub-apical leaves of soybean for an increment of chlorophyll content (Ghafariyan et al. 2013). Kokina et al. (2020) studied the exposure of different sizes of iron oxide nanoparticles (FeONPs) on yellow medick (*Medicago falcata* L.) plants. The observed results indicated a significant increase in chlorophyll α fluorescence, plant root length, induced genotoxicity, and reduced genome stability compared to the control plant. Moreover, enhanced miR159c expression indicated enhanced plant resistance against fungal pathogens.

19.3.6 Manganese Nanoparticles

Manganese (Mn) micronutrient is primarily essential for the photosynthesis process in plants. Pradhan et al. (2013) observed the effect of manganese nanoparticles (MnNPs) on leguminous plant *Vigna radiate* (L.) R. Wilczek at a specific concentration as compared to conventionally available manganese salt, $MnSO_4$ under laboratory conditions. The higher concentration of MnNP had not induced phytotoxicity to the plant and the size of MnNP possibly helped plants to uptake these nanoparticles more easily and translocated itself in the leaves using xylem. The MnNPs treated chloroplasts increased the function of CP43 protein in the reaction center of photosystem II (PS II) and had shown higher photophosphorylation, where oxygen was generated by water molecule splitting and also enhanced the electron transport chain.

Manganese hollow core shell nanoparticles have used for the controlled and targeted release of zinc (Zn) to the plant (*Oryza sativa* L.) soil. The result indicated that the nano-sized manganese hollow core shell enhances and improve Zn uptake by rice plant and reduce the loss of nutrients (Yuvaraj and Subramanian 2015).

19.3.7 Magnesium Nanoparticles

Magnesium nanoparticles (MgNPs) used as an alternate of Mg in the *Vigna unguiculata* (L.) Walp. plant, which enhanced the seed weight and yield (Delfani et al. 2014). Further, a study was conducted by Rathore and Tarafdar (2015), on the controlled delivery of magnesium nanoparticles (MgNPs) to wheat plants. The foliar application of MgNPs on plant increased the light absorption on the leaf surface and it also improved different enzyme activities which resulted in the enhanced mobilization of nutrients (Fe, Cu, Zn, P, and Mg) uptake. It also significantly improved the wheat plant root length and biomass. Magnesium oxide nanoparticles (MgONPs) (15 nm) enhanced seed germination and growth rate mechanism in *Arachis hypogaea* L. at 0.5 mg/L concentrations by penetrating seeds coat and internally support water retention in seeds which increased biomass production for the plant (Jhansi et al. 2017).

19.3.8 Molybdenum Nanoparticles

The colloidal solution of molybdenum nanoparticles (MoNPs) enhances plant resistance and also increased crops productivity due to the active uptake of nanoparticle into the plant cells. The experimental studies showed when the *Cicer arietinum* L. seeds were treated with MoNPs (colloidal solution) it enhanced the formation of nodule per plant by four fold as compared to control (Taran et al. 2014). Thomas et al. have also studied (2017), the effect of MoNPs (2–7 nm) on *Cicer arietinum* L. plant at 4 ppm concentration. The results showed a significant improvement in the root area, diameter, length, perimeter, and tips number. It also enhanced microbial activities and useful enzymes along with increased biomass and grain yield.

19.3.9 Silicon Nanoparticles

Silicon nanoparticles (SiNPs) application has used for Basil plant to reduce the pollution caused by salinity (*Ocimum basilicum* L.). SiNPs significantly increased the chlorophyll and reduced proline content in basil (Kalteh et al. 2018). Tripathi et al. 2015 studied the shielding effect of SiNP for *Pisum sativum* L. against chromium Cr(VI) phytotoxicity. The results showed that SiNPs reduced the accumulation of Cr in roots and shoots and enhances the intake of mineral nutrients which possess antioxidant activity and also reduces the ROS level. According to the study of Ali et al. (2019) SiNPs have the ability to restrain the accumulation of cadmium (Cd) concentrations in *Triticum aestivum* L. grain and other parts of the plant. Moreover, SiNPs improved the development, photosynthesis and also reduced the oxidative stress of wheat grain and in future, it can also be used as a fertilizer for controlling metal accumulation in crop plants.

19.3.10 Titanium Dioxide Nanoparticles

The comparative study of nano-TiO_2 and TiO_2 was investigated on the enlargement and germination of naturally-aged spinach seed (*Spinacia oleracea* L.) (Zheng et al. 2005). The experimental studies indicated that at a certain concentration nano-TiO_2 treated spinach seed enhances the germination of the aged seeds. The 30 days nano-TiO2 effect on spinach plants showed a 73% increase in dry weight, improves the chlorophyll formation up to 45% and enhances the photosynthetic rate three times as compared to the control during the germination stage. This effect of the development rate of spinach seeds was inversely proportional to the size of TiO_2 signifying, smaller the nanoparticle different the germination growth. Furthermore, the researcher defines the possibility of entry of nano-TiO_2 into cells those have increased oxidation–reduction reactions via the superoxide ion radical during germination in the dark and resulted in the quenching of free radicals during the germination of seeds,which also increased the photosynthetic rate. Effect of TiO_2NP on coriander plant (*Coriandrum sativum* L.) at concentration dependent manner improved the nutritional quality, enhanced root and shoot fresh biomass (Hu et al. 2020).

19.3.11 Zinc Nanoparticles

Zinc oxide nanoparticles (ZnONPs) have been used in industry for the last many years. Zn is the most important vital micronutrient that is mandatory to enhance the crop productivity. Prasad et al. (2012) investigated the effect of Zn micronutrient into peanut seeds through ZnONPs (25 nm mean particle size). It improves the uptake of Zn through leaf and kernel and a high content of Zn was found in the seed and increase chlorophyll amount in leaf. These nanoparticles proved helpful in enhancing stem and root growth (Prasad et al. 2012). Lin and Xing (2007), reported ZnONPs significantly adhered to the root surface and enter inside the plant cell through penetration and found in the apoplast and protoplast of the root endodermis and stele. Rawashdeh et al. (2020) studied effect of two different concentrations of ZnONPs (25 ppm or 50 ppm) on Lettuce seeds (*Lactuca sativa* L.). The obtained results showed enhanced seed germination, and biomass of seeds due to stimulated catalase enzyme activity.

19.4 Conclusion and Prospects

The sustainable agriculture, nutrient safety, and food accessibility are included the key sustainable development objectives to cope the crop nutrient deficiency. Hence, it is necessary to exploit the benefits of nanotechnology in reaching the feat by enhancing plant nutrient accessibility and reducing their losses on agricultural field. Nanobiotechnology application plays a notable role in agriculture to manage nutrient deficiency stress for crop management which is necessary for sustainable agriculture. It could be significantly enhanced nutritional health and sanitation of crops simultaneously, improved food security and sustainability in the coming times. Nanobiotechnology has a multidirectional approach therefore, it is necessary to exploit the benefits of its application in reaching the feat by enhancing plant nutrient accessibility and reducing their losses on the agricultural field. Previous studies indicated that the mineral nanoparticles are beneficial for plant growth efficiency, root enhancement, chlorophyll content, uptake of mineral, regulation of phytohormone contents and antioxidant enzyme activity, enhanced gene expression, and seed development. Additionally, it is also beneficial for inhibition of accumulation of heavy metals concentration inside the plants. Although the obtained results are limited to the experimental level, therefore it is necessary to introduce the application of nanofertilizer in the nursery stage to proceed towards a large-scale agriculture field. More scientific research studies required to analyze the environmental risks of nanoparticles to encourage the safe development of nanofertilizer. Hence, nanotechnology is a promising sector to provide commercialized nanofertilizers for better crop productivity and soon that will be available in the market.

References

Adhikari T, Kundu S, Biswas AK et al (2015) Characterization of zinc oxide nano particles and their effect on growth of maize (Zea mays L.) plant. J of Pla Nut 38(10):1505–1515

Adhikari T, Sarkar D, Mashayekhi H, Xing B (2016) Growth and enzymatic activity of maize (Zea mays L.) plant: solution culture test for copper dioxide nano particles. J of P Nut 39(1):99–115

Ali S, Rizwan M, Hussain A et al (2019) Silicon nanoparticles enhanced the growth and reduced the cadmium accumulation in grains of wheat (Triticum aestivum L.). Pla Phys and Biochem 140:1–8

Ashraf M, Akram NA, Al-Qurainy F, Foolad MR (2011) Drought tolerance: roles of organic osmolytes, growth regulators and mineral nutrients. Adv in Agr 111:249–296

Baloch OB, Chacar OI, Tareen MN (2008) Effect of foliar application of macro and micronutrients on production of green chilies (Capcicum annuum L.) J Agric Tech 4(2):177–184

Baruah S, Dutta J (2009) Nanotechnology applications in pollution sensing and degradation in agriculture: a review. EnvChem Let. 7(3):191–204

Bernal M, Cases R, Picorel R, Yruela I (2007) Foliar and root Cu supply affect differently Fe and Zn-uptake and photosynthetic activity in soybean plants. Environ Exp Bot 60:145–150

Bhatt D, Bhatt MD, Nath M et al (2020) Application of nanoparticles in overcoming different environmental stresses. Protective chemical agents in the amelioration of plant abiotic stress: Biochemical and molecular perspectives, 635–654

Burman U, Saini M, Kumar P (2013) Effect of zinc oxide nanoparticles on growth and antioxidant system of chickpea seedlings. Tox & Env Chem 95(4):605–612
Chhipa H (2017) Nanofertilizers and nanopesticides for agriculture. Env Chem Let 15(1):15–22
Delfani M, Firouzabadi MB, Farrokhi N, Makarian H (2014) Some physiological responses of black-eyed pea to iron and magnesium nanofertilizers. Commun Soil Sci Plant Anal 45:11
Dimkpa CO, Bindraban PS (2017) Nanofertilizers: new products for the industry?. J Agric Food Chem 66(26):6462–6473
Eichert T, Kurtz A, Steiner U, Goldbach HE (2008) Size exclusion limits and lateral heterogeneity of the stomatal foliar uptake pathway for aqueous solutes and water-suspended nanoparticles. Phy Pla 134(1):151–160
Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO (2019) The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. App Sci 9(3):499
Elmer W, White JC (2018) The future of nanotechnology in plant pathology. Ann Rev Phyto 56:111–133
Ghafariyan MH, Malakouti MJ, Dadpour MR et al (2013) Effects of magnetite nanoparticles on soybean chlorophyll. Envir Sci Tec 47(18):10645–10652
Ghormade V, Deshpande MV, Paknikar KM (2011) Perspectives for nano-biotechnology enabled protection and nutrition of plants. Biotec Adva 29(6):792–803
Gruère GP (2012) Implications of nanotechnology growth in food and agriculture in OECD countries. F Pol 37(2):191–198
Gutiérrez FJ, Mussons ML, Gatón P, Rojo R (2011) Nanotechnology and food industry. In: Valdez B, Schorr M, Zlatev R (eds) Scientific, health and social aspects of the food industry. InTech, pp 95–128
Hafeez A, Razzaq A, Mahmood T, Jhanzab HM (2015) Potential of copper nanoparticles to increase growth and yield of wheat. J Nanosci Adv Technol 1(1):6–11
Handford CE, Dean M, Henchion M et al (2014) Implications of nanotechnology for the agri-food industry: opportunities, benefits and risks. Tre in F Sci Tech 40(2):226–241
Hu J, Wu X, Wu F et al (2020) Potential application of titanium dioxide nanoparticles to improve the nutritional quality of coriander (Coriandrum sativum L.). J of hazar mater 389:121837
Hu M, Zhao X, Liu Q et al (2018) Transgenic expression of plastidic glutamine synthetase increases nitrogen uptake and yield in wheat. Pla Biotec J 16(11):1858–1867
Hua KH, Wang HC, Chung RS, Hsu JC (2015) Calcium carbonate nanoparticles can enhance plant nutrition and insect pest tolerance. J of Pest Sci 40(4):208–213
Ion AC, Ion I, Culetu A (2010) Carbon-based nanomaterials: Environmental applications. Uni Pol Buch 38:129–132
Jhansi K, Jayarambabu N, Reddy KP et al (2017) Biosynthesis of MgO nanoparticles using mushroom extract: effect on peanut (Arachis hypogaea L.) seed germination. 3 Biotec 7(4):263
Joseph T, Morrison M (2006) Nanotechnology in agriculture and food. Nano Rep 2:2–3
Kalteh M, Alipour ZT, Ashraf S et al (2018) Effect of silica nanoparticles on basil (Ocimum basilicum) under salinity stress. J Chem Health Risks 4(3):49–55
Kashyap PL, Xiang X, Heiden P (2015) Chitosan nanoparticle based delivery systems for sustainable agriculture. Int J Bio Mac 77:36–51
Khot LR, Sankaran S, Maja JM et al (2012) Applications of nanomaterials in agricultural production and crop protection: a review. C Pro 35:64–70
Kokina I, Plaksenkova I, Jermaļonoka M, Petrova A (2020) Impact of iron oxide nanoparticles on yellow medick (Medicago falcata L.) plants. J of Pla Inter 15(1):1–7
Kottegoda N, Munaweera I, Madusanka N, Karunaratne V (2011) A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. Cuur Sci 101(1):73–78
Kuzma J (2007) Moving forward responsibly: Oversight for the nanotechnology-biology interface. J Nano Res 9(1):165–182
Lin D, Xing B (2007) Phytotoxicity of nanoparticles: inhibition of seed germination and root growth. Env Pol 150(2):243–250

Lin D, Xing B (2008) Root uptake and phytotoxicity of ZnO nanoparticles. Env Sci Tech 42(15):5580–5585
Liu R, Lal R (2014) Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (Glycine max). Sci Rep 4:5686
Liu X, Zhang F, Zhang S et al (2004) Responses of peanut to nano-calcium carbonate. Plant Nutr Fertil Sci 11:385–389
Liu X, Zhang F, Zhang S et al (2005) Responses of peanut to nano calcium.carbonate. P Nut Fer Sci 11(3):385–389
Maathuis FJM (2009) Physiological functions of mineral macronutrients. Curr Opin Plant Bio 12:250–258
Mahajan P, Dhoke SK, Khanna AS (2011) Effect of nano-ZnO particle suspension on growth of mung (*Vigna radiata*) and gram (*Cicer arietinum*) seedlings using plant agar method. J Nano 2011:1–7
Marschner H (2012) Mineral nutrition of higher plants, 3rd edn. Academic, London, UK
Martin A, Leeb J, Kicheyc T et al (2006) Two cytosolic glutamine synthetase isoforms of maize are specifically involved in the control of grain production. Pla C 18:3252–3274
Millán G, Agosto F, Vázquez M (2008) Use of clinoptilolite as a carrier for nitrogen fertilizers in soils of the Pampean regions of Argentina. Int J Agr Nat Res 35(3):293–302
Mortvedt JJ (1992) Crop response to level of water-soluble zinc in granular zinc fertilizers. Fert Res 33(3):249–255
Mukhopadhyay SS (2014) Nanotechnology in agriculture: prospects and constraints. Nano Sci App 7:63
Nair R, Varghese SH, Nair BG et al (2010) Nanoparticulate material delivery to plants. Pla Sci 179(3):154–163
Navrotsky A (2000) Nanomaterials in the environment, agriculture, and technology (NEAT). J of Nano Res 2(3):321–323
Nel A, Xia T, Madler L, Li N (2006) Toxic potential of materials at the nanolevel. Sci 311: 622–627
Ohkama-Ohtsu N, Wasaki J (2010) Recent progress in plant nutrition research: cross-talk between nutrients, plant physiology and soil microorganisms. Pl Cel Phy 51(8):1255–1264
Owolade O, Ogunleti D (2008) Effects of titanium dioxide on the diseases, development and yield of edible cowpea. J of P Prot Res 48(3):329–336
Pandey AC, Sanjay SS, Yadav SR (2010) Application of ZnO nanoparticles in influencing the growth rate of Cicer arietinum. J of Exp Nano 5(6):488–497
Parisi C, Vigani M, Rodríguez-Cerezo E (2015) Agricultural nanotechnologies: what are the current possibilities? Nano Tod 10(2):124–127
Pradhan S, Patra P, Das S et al (2013) Photochemical modulation of biosafe manganese nanoparticles on Vignaradiata: a detailed molecular, biochemical, and biophysical study. Env Sci Tech 47(22):13122–13131
Prasad R, Bhattacharyya A, Nguyen QD (2017) Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. Fron in Mic 8:1014
Prasad R, Kumar V, Prasad KS (2014) Nanotechnology in sustainable agriculture: present concerns and future aspects. AfrJou of Bio 13(6):705–713
Prasad TNVKV, Sudhakar P, Sreenivasulu Y et al (2012) Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. J P Nut 35(6):905–927
Puoci F, Lemma F, Spizzirri UG et al (2008) Polymer in agriculture: A review. Am J Agri Bio Sci 3:299–314
Rajemahadik VA (2018) Nanotechnology: Innovative approach in crop nutrition management. Int J Agr Sci ISSN: 0975–3710
Raliya R, Tarafdar JC (2013) ZnO nanoparticle biosynthesis and its effect on phosphorous-mobilizing enzyme secretion and gum contents in Cluster bean (Cyamopsistetragonoloba L.). Agr Res 2(1): 48–57

Ramírez-Rodríguez GB, Dal Sasso G, Carmona FJ et al (2020) Engineering biomimetic calcium phosphate nanoparticles: A green synthesis of slow-release multinutrient (NPK) Nanofertilizers. ACS App Bio Mat 3(3):1344–1353
Ranathunge K, El-kereamy A, Gidda S et al (2014) OsAMT1;1 transgenic rice plants with enhanced NHþ4 permeability show superior growth and higher yield under optimal and suboptimal NHþ4 conditions. J Exp Bot 65:965–979
Rane M, Bawskar M, Rathod D et al (2015) Influence of calcium phosphate nanoparticles, Piriformospora indica and Glomus mosseae on growth of Zea mays. Advances in natural sciences: Nanosci Nanotec 6(4):
Rathore I, Tarafdar JC (2015) Perspectives of biosynthesized magnesium nanoparticles in foliar application of wheat plant. J Bionano 9(3):209–214
Rawashdeh RY, Harb AM, AlHasan AM (2020) Biological interaction levels of zinc oxide nanoparticles; lettuce seeds as case study. Heli 6(5):
Robinson DKR, Morrison MJ (2009) Nanotechnology developments for the agrifood sector - report of the observatory, NANO. May 2009. www.observatorynano.eu
Roco MC (2011) The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years. J Nanopart Res 13:427–445
Rui M, Ma C, Hao Y et al (2016) Iron oxide nanoparticles as a potential iron fertilizer for peanut (Arachis hypogaea). Fron in Plan Sci 7:815
Schachtman DP, Shin R (2007) Nutrient sensing and signaling: NPKS. Ann Rev Plant Biol 58:47–69
Scott N, Chen H (2013) Nanoscale science and engineering for agriculture and food systems. Ind Biotechnol 9:17–18
Shah V, Belozerova I (2009) Influence of metal nanoparticles on the soil microbial community and germination of lettuce seeds. Wat A S Poll 197(1–4):143–148
Shende S, Rathod D, Gade A, Rai M (2017) Biogenic copper nanoparticles promote the growth of pigeon pea (Cajanus cajan L.). IET Nanobiotec 11(7):773–781
Tantawy AS, Salama YAM, Abdel-Mawgoud MR, Ghoname AA (2014) Comparison of chelated calcium with nano calcium on alleviation of salinity negative effects on tomato plants. Mid E Jou of Ag Res 3(4):912–916
Taran NY, Gonchar OM, Lopatko KG et al (2014) The effect of colloidal solution of molybdenum nanoparticles on the microbial composition in rhizosphere of Cicer arietinum L. Nanos Res Let 9(1):289
Thakur S, Thakur S, Kumar R (2018) Bio-nanotechnology and its role in agriculture and food industry. J Mol Genet Med 12:324 https://doi.org/10.4172/1747-0862.1000324
Thomas E, Rathore I, Tarafdar JC (2017) Bioinspired Production of Molybdenum Nanoparticles and Its Effect on Chickpea (Cicer arietinum L). J of Bionanosc 11(2):153–159
Torney F, Trewyn BG, Lin VSY, Wang K (2007) Mesoporous silica nanoparticles deliver DNA and chemicals into plants. Nat Nano 2(5):295
Tripathi DK, Singh VP, Prasad SM et al (2015) Silicon nanoparticles (SiNp) alleviate chromium (VI) phytotoxicity in Pisum sativum (L.) seedlings. Pla Phys and Biochem. 96:189–198
Yuvaraj M, Subramanian KS (2015) Controlled-release fertilizer of zinc encapsulated by a manganese hollow core shell. Soil Sci Pl Nut 61(2):319–326
Zeng H, Wang G, Hu X et al (2014) Role of microRNAs in plant responses to nutrient stress. Pla and Soil 374(1–2):1005–1021
Zhao L, Peralta-Videa JR, Rico CM et al (2014) CeO2 and ZnO nanoparticles change the nutritional qualities of cucumber (Cucumis sativus). J Agr Food Chem 62(13):2752–2759
Zheng L, Hong F, Lu S, Liu C (2005) Effect of nano-TiO2 on strength of naturally aged seeds and growth of spinach. Bio Trace Elem Res 104(1):83–91