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15 New Approach to Utilize Nano-Micronutrients in Sugar Beet (*Beta vulgaris* L.)

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Abstract

Nano-fertilizers are more efficient and eco-friendly when compared with the other forms of chemical fertilizers. Using nano-fertilizers as a source of needed nutrients has advantages in crop production. Nano-fertilizers have a great impact on crops and soils. They reduce the toxicity of the soil, decrease the frequency of fertilizer application, and increase crop productivity. A clear understanding of sugar beet response to nano-micronutrients may help in programs aiming at yield and quality traits evaluation. In this chapter, we focused on the importance of nano-micronutrients including iron, magnesium, silicon, zinc, copper, and boron in crop production using sugar beet as a case study. In addition, interactive effects of nano-micronutrients as fertilizers are also discussed and reported. Nano-micronutrients application promoted the growth, development, yield, and quality traits of sugar beet and has the potential to improve crop production and plant nutrition. Nano-fertilizations can gradually provide the crops with their essential nutrients and can be of environmental and economic significance in comparison to chemical fertilization.

Keywords

Boron · Iron · Manganese · Micronutrients · Nano-fertilizers · Zinc

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Abbreviations

B	Boron
Cl	Chlorine
Cu	Copper
EDTA	Ethylene diamine tetra acetic acid
ENPs	Engineered nanoparticles
Fe	İron
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
NMs	Nanomaterials
TSS	Total soluble solids
Zn	Zinc

15.1 Introduction

Nanotechnology is a novel beneficial discovery; it may provide keener solutions for the current problems in the field of agriculture. Nanotechnology concepts can help farmers to know the effects before and input solutions for a better after (Rameshaiah et al. 2015). Nanotechnology is one of the new technologies that entered almost all aspects of our lives and were used in agriculture production. Nanotechnology has the potential to increase food quality, raise global food production, protect plants, detect plant and animal diseases, and monitor plant growth and waste reduction for "sustainable amplification" (Khan and Rizvi 2017). This technology is used in all stages of the production of agricultural products such as processing, packaging, transport, and storage. It is used in the detection and control of diseases. One of the most important uses of nanotechnology is in the field of plant fertilization (Mousavi and Rezaei 2011; Srilatha 2011; Ditta 2012). The aim of the application of nanomaterials in agriculture is to reduce the applied amount of plant protection products, minimize the nutrient loss in fertilization, and increase the yield through optimized nutrient management (Predoi et al. 2020).

Sugar beet (*Beta vulgaris* L.) belongs to Chenopodiaceae family. It is a biennial plant and one of the most important sugar crops in the world (Watson and Dallwitz 1992). Sugar beet ranks as the world's second important sugar crop. The great importance of the sugar beet crop is underlined in its ability to grow in the newly reclaimed areas as economic crop and its ability to produce high sugar yield (Hassnein et al. 2019). Sugar beet plants fertilized with micronutrients achieved the highest root and sugar production (Abd El-Hadi et al. 2002; Ramadan and Nassar 2004; Nemeat-Alla and Mohamed 2005; Nemeat-Alla et al. 2009; Moustafa et al. 2011; Amin et al. 2013; Abbas et al. 2014, 2020; Hassnein et al. 2019). Also, Asadzade et al. (2015) and Mekdad and Rady (2016) mentioned that adding micronutrient mixtures (Fe, Zn, and Mn) has improved yield and other attributes of sugar beet crop. Nemeat-Alla et al. (2014) showed that micronutrients application gave the maximum yield and quality for sugar beet crop. Contrary, deficiency of soil nutrients such as macro- and micronutrients should be added to the rhizosphere according to plant needs and has been known as the major limitations in beet crop production (Abido 2012). Also, the sugar beet exhibits the greatest sensitivity to the deficiency of micronutrients in the soil (Christenson and Draycott 2006). Therefore, the current chapter presents a review of evidence related to the roles of nano-fertilizers in sugar beet production and management.

15.2 Definition of Nano-Fertilization

Nano-fertilizers are known as nanomaterials that can provide nutrients to plants or help to increase the activity of traditional fertilizers without direct contact with crops. Nano-fertilizers are new generation of the synthetic fertilizers which contain readily available nutrients in nano scale range (Janmohammadi et al. 2016), which improves the ability of plants to absorb nutrients (Mousavi and Rezaei 2011; Srilatha 2011; Ditta 2012).These materials have unique properties of very small size ranging from 8 μm to 10 nm (Das et al. 2004), Also, engineered nanoparticles (ENPs) are able to enter plant cells and leaves, and can also transfer DNA and chemicals in plant cells (Galbraith 2007; Torney et al. 2007). Nano-fertilizers are one potential output that could be a major innovation for agriculture; the large surface area and small size of the nanomaterials could allow for enhanced interaction and efficient uptake of nutrients for crop fertilization (DeRosa et al. 2010). The integration of nanotechnology in fertilizer products may improve release profiles and increase uptake efficiency, leading to significant economic and environmental benefits.

Subramanian et al. (2015) indicated that nano-fertilizers are nutrient carriers of nano-dimensions ranging from 30 to 40 nm and capable of holding bountiful of nutrient ions due to their high surface area and release it slowly and steadily that commensurate with crop demand. However, Chhipa and Joshi (2016) reported that nano-fertilizers are divided into three categories. These are macro-nano-fertilizers, micro-nano-fertilizers, and nanoparticulate fertilizers, depending on nutrient requirements of the plants. Also, nanostructured fertilizers in the form of nanocarriers, nano-capsules, and nano-nutrients could be considered as smart fertilizers, which can enhance the efficiency of plant nutrients use, control the nutrients release, and reduce the environmental pollution (Yaseen et al. 2020).

A nano-fertilizer is any product that is made with nanoparticles or uses nanotechnology to improve nutrient efficiency. Nano-fertilizers are being studied as a way to increase nutrient efficiency and improve plant nutrition, compared with traditional fertilizers (Mikkelsen 2018). Current applications of nanotechnology in fertilizer and plant protection can be divided into three categories (Mastronardi et al. 2015):

(a) Nanoscale fertilizer inputs: This category describes examples of a nanosized reformulation of a fertilizer input. The fertilizer or supplement is reduced in size, using mechanical or chemical methods, down to the nanoscale. The input is typically in the form of nanoparticles but may also be in other forms.

(b) Nanoscale additives: This category includes examples where the nanomaterials are added to bulk (>100 nm scale) product. These nanomaterials may be a supplement material added for an ancillary reason, such as water retention or pathogen control in plants or soils.

(c) Nanoscale coatings or host materials for fertilizers: This category describes nano-thin films or nano-porous materials used for the controlled release of the nutrient input. These include, for example, zeolites, other clays, and thin polymer coatings.

15.3 The Importance and Advantages of Nano-Fertilization

Lin and Xing (2007) and Navarro et al. (2008) attributed the high proficiency of the nano-fertilizers to:

- Reactivity of nanomaterials with the other compounds is higher than those of ordinary ones, due to their higher surface area and very less particles size, which provides more sites for plant metabolism.
- Enhancement of nutrients penetration and plant uptake, due to the reduced size of the NPs, that increased its specific surface area and particle numbers per unit, which led to increasing the contact surface between the nano-fertilizers and the plants.

Many studies showed that the use of nano-fertilizers causes an increase in nutrients use efficiency, reduces soil toxicity, minimizes the potential negative effects associated with over dosage, and reduces the frequency of the application. Hence, nanotechnology has a high potential for achieving sustainable agriculture, especially in developing countries (Nadzri and Danesh-Shahraki 2013).

Zulfiqar et al. (2019) mentioned that nano-fertilizers offer benefits in nutrition management through their strong potential to increase nutrient use efficiency. Nutrients, either applied alone or in combination, are bound to nano-dimensional adsorbents, which release nutrients very slowly as compared to conventional fertilizers. This approach not only increases nutrient use efficiency, but also minimizes nutrient leaching into ground water. Furthermore, nano-fertilizers may also be used for enhancing abiotic stress tolerance and used in combination with microorganisms (the so-called nano-biofertilizers) to provide great additional benefits.

Conley et al. (2009) mentioned that the aim of using nanomaterials (NMs) in agriculture is to improve the efficiency and sustainability of agricultural practices by developing fewer inputs and generating less waste in comparison to traditional products and approaches, fertilizers are vital for plant growth and development. Most of the added fertilizers remain unavailable to plants due to several factors such as leaching and degradation by hydrolysis, solubility, and decomposition. The addition of traditional fertilizers at a high- and long-term rate in agriculture has caused major environmental issues around the world.

Nano-fertilizers stand as increasing intelligent materials that enhance nutrients phytoavailability of crops (Jahan 2018). Application of nano-fertilizers may improve solubility and dispersion of insoluble nutrients in soil, reduce nutrient immobilization (soil fixation), and increase the bioavailability (Naderi and Danesh-Shahraki 2013)**.** However, Tavan et al. (2014) reported that the use of nano-fertilizers to precisely control nutrient releases an effective step in achieving sustainable and environmentally friendly agriculture.

Guru et al. (2015), showed that the common features of nano-fertilizers including:

- Delivering the appropriate nutrients for enhancing the plant growth through foliar and soil applications.
- Eco-friendly sources of plant nutrients and of low cost.
- Have high efficiency of fertilization process.
- Have a supplementary role with mineral fertilizers.
- Protect the environment from pollution hazards.
- Nano-fertilizers help us to eliminate the contamination of drinking water and could be considered as emerging alternatives of the conventional fertilizers.

Nano-fertilizers play an important role where the ancient chemical fertilizers are replaced with nano and biofertilizers and preferred largely due to their efficiency and environment friendly nature compared to conventional chemical fertilizers (Janmohammadi et al. 2016). Primary use of adding is fast uptake of nutrients from the soil and giving better, faster yield. The symbiotic exchange between soil and the plant system is very efficient. When the same is applied in slow and efficient way, all the required nutrients are taken up by the plant and restores the required and efficient energy in it for which the yield increases drastically (Rameshaiah et al. 2015).

Recent studies revealed that nano-fertilizers can make strides both on germination of seeds and on development of seedlings. This is attributed to its capacity to enter the seeds effectively and to increment accessibility of diverse supplements into the developing seedlings (Antar and Igor 2018). In addition, Boutchuen et al. (2019) revealed that there is an emerging scientific interest in the use of nanoparticle fertilizers for enhanced agricultural and bioenergy crop production to meet the growing food and energy demands of the world. The objective of designing the nanoparticle fertilizers is to effectively deliver the required nutrients for the plants without adding large quantities of fertilizer to the environment. The use of nanoscale micronutrients conduced to suppressing crop disease and the relationship between nutritional status and plant diseases is investigated. Nanomaterials are capable to penetrate into cells of herbs; they can carry DNA and other chemical compounds in the cells extending the possibility in plant biotechnology to target special gene manipulation (Predoi et al. 2020).

15.4 Using the Nanotechnology Image on Micronutrients Fertilizers

Barker and Pilbeam (2007) revealed that micronutrients are those trace elements which are essential for the normal healthy growth and reproduction of plants and animals. The trace elements essential for plants are boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Differences in the efficiency with which crop varieties are able to utilize low supplies of B, Cu, Mn, Fe, and Zn have resulted in them being labelled as being either "efficient" or "inefficient" for a specific micronutrient (Alloway 2008).

Micronutrients play an important role in various physiological, metabolic, and cellular processes in plants as these transition metals have unpaired electrons that promote oxidation and reduction reactions (Zargar et al. 2015). Several research studies reported that nanoscale of Fe_2O_3 and ZnO application in different plant. i.e. pumpkins (Zhu et al. 2008), mung beans and chickpeas, (Mahajan et al. 2011) peanuts, (Prasad et al. 2012) tomatoes, (Giordani et al. 2012) soybeans, (Sheykhbaglou et al. 2010; Lopez-Moreno et al. 2010; Ghafariyan et al. 2013; Alidoust and Isoda 2013) cucumbers, (Raliya and Tarafdar 2013) watermelons, (Wang et al. 2013; Li et al. 2013) clover, (Feng et al. 2013) wheat, (Ramesh et al. 2014) rice, (Upadhyaya et al. 2017; Jaksomsak et al. 2018) beans, (Dimkpa et al. 2017) maize, (Subbaiah et al. 2016) cotton (Venkatachalam et al. 2017) and black gram (Raja et al. 2019).

Much recent research on nanoparticles in a number of crops has evidence for enhanced germination and seedling growth, physiological activities, gene expression, and protein level indicating their potential use in crop improvement (Kole et al. 2013). Janmohammadi et al. (2016) said that results revealed that days to a thesis and maturity of barley significantly increased after application of nano-fertilizers. Also, Ali and Al-Juthery (2017) reported that nano-fertilizers enhance growth parameters (plant height, leaf area, number of leaves per plant) dry matter production, chlorophyll production, rate of the photosynthesis which result more production and translocation of photosynthesis to different parts of the plant compared with traditional fertilizers. Nanoparticles enhance crop yield, photosynthetic activity, nutrient use efficiency, grain quality, and nitrogen metabolism (Sekhon 2014).

Use of nano-fertilizers instead of common fertilizers may have properties that are valuable to crops which releases the nutrients requirement, discharge of chemicals fertilizers in a controlled way that standardize plant growth and improve activity of target (Farooqut et al. 2016). Also, Farahat et al. (2007) reported that the nano-micronutrients form an important micronutrient needed in small amounts by crop plants. Its important roles in various metabolic and physiological processes in the plant, where it activates some enzymes, regulate metabolism of carbohydrates and proteins, which are essential for various processes, critical to development and differentiation of plant cells. Researchers reported that using nano-fertilizer leads to impressive reductions in nitrogen related environmental harms and an increase in nitrogen use efficiency, resulting in crops yield increases (Gammon 2017). However, Kalra et al. (2020) found that the nano-encapsulated micronutrients that facilitate increased nutrient utilization efficiency have several properties:

- They possess large surface area because of very small size of particles, thus providing it more area to ease distinct metabolic process in the plant system resulting in production of more photosynthetic products.
- They have high reactivity with other compounds because of wide surface area and very minute size of particles.
- They are highly soluble in solvent such as water.
- They penetrate more into the plant due to nano-fertilizers' particle size less than 100 nm.
- They improve uptake capacity and efficiency of nutrient utilization due to large surface area of nano-fertilizer.
- Nanoparticles encapsulating fertilizers within themselves will hasten the bioavailability and uptake.

Dey et al. (2018) indicated that the loading of nutrients on the nanoparticles is usually done by:

(a) Absorption on nanoparticles.
(b) Attachment on nanoparticles mediated by ligands.
(c) Encapsulation in nanoparticulate polymeric shell.
(d) Entrapment of polymeric nanoparticles.
(e) Synthesis of nanoparticles composed of the nutrient itself.

15.4.1 Zinc (Zn)

It is absorbed by roots as a cation (Zn^{+2}) and as a component of synthetic and natural organic complexes. Its concentration in plants ranges between 25 and 150 ppm. Zinc is important for the synthesis of tryptophane, a component of some proteins and a compound needed for the production of growth hormones (auxins) such as indole acetic acid and gibberellic acid. It is involved in enzyme systems and metabolic reactions. It is necessary for the production of chlorophyll and carbohydrates (Dey et al. 2018). Zinc is involved in hormone biosynthesis, cytoplasm synthesis, activation and function of different enzymes, protein synthesis (Noaema and Barbara 2018). Zinc is an essential micronutrient that produces growth hormones and chloroplast (Palmer and Guerinot 2009). Also, Zn plays a vital role in plant and the most important biochemical and physiological functions of Zn in plants include: participation in biosynthesis of tryptophan—the precursor of auxins; control of carbonic anhydrase; activation of RNA polymerase; stabilization of cytoplasmic membranes; control of oxidative stress through superoxide dismutase and increased plants resistance to water stress (Khan et al. 2004; Lošák et al. 2011; Hafeez et al. 2013).

Nanotechnology plays an important role for the same nano particles which can be used to coat zinc in order to get diffused and soluble zinc (Milani et al. 2010). The effect on different plants of the foliar exposure to nanomaterials as ZnO conduced to increase in shoot length, root length, increase in chlorophyll, soluble leaf protein or increase in acid phosphatase, alkaline phosphatase and phytase (Khodakovskaya et al. 2011; Tarafdar et al. 2014). Application of zinc nano-fertilizer increased the grain mass up to 6% over to control. The higher 1000 grain mass indicates increased individual grain sink strength. The sink strength can be depicted as the output of sink activity and sink size (Yang et al. 2003). Malik and Kumar (2014) indicated that equal ratios between surface area and size of nano particles should be carefully designed if not, total solubility of the zinc will be affected. This is shown by taking ratio of Nano-ZnO and bulk ZnO available on whole. Tarafdar et al. (2014) who suggested that application of zinc nano-fertilizer on pearl millet (*Pennisetum americanum* L.) significantly improved shoot length, root length, root area, chlorophyll content, total soluble leaf protein, plant dry biomass, and increased the grain yield by 37.7%. Marzouk et al. (2019) indicated that the foliar application of zinc nano-fertilizer increased the studied characteristics for snap bean (the highest values of vegetative growth, fresh pod yield, pod physical quality (length, diameter, and fresh weight), dry weight, and pod nutritional value content expressed as P, K, Zn, Mn, Fe, Cu, crude protein, total soluble solids, and fiber) significantly compared with other nano-micronutrients. Also, the combined effect of Flantino cultivar with zinc nano-fertilizer treatment recorded the highest values of vegetative growth, fresh pod yield, pods physical quality, and nutritional value. Rizwan et al. (2019) said that experimental application of ZnO nanoparticles improved the activities of antioxidant enzymes in leaves and roots. Generally, revealing that ZnO nanoparticles with effect in maize biomass and growth are expressed by accelerated exogenous application of nanoparticles further enhanced with biochar application in combination to nanoparticles.

ZnO NPs is nanomaterial with intense antimicrobial activity that is effective to pathogen control growth, also characterized by a lower toxicity in comparison to Ag and with benefits on soil fertility. The application of ZnO NPs conduced to systemic disruption of cellular function of pathogens as *Botrytis cinerea* or *Penicillium expansum* resulting in hyphal malformation and fungal depth (He et al. 2011). In addition, Raliya and Tarafdar (2013) and Raliya et al. (2015a, b) showed that ZnO NPs increased seed germination and seedling vigor and also increased the stem and root growth. Early germination and establishment of seeds in the soil caused early flowering and promoted leaf chlorophyll content. Foliar treatment of ZnO NPs to *Cyamopsis tetragonoloba* and *Solanum lycopersicum* has shown a positive response in terms of biomass production and the chlorophyll and total soluble leaf protein contents. Shaban et al. (2019), showed that the common bean that is obtained from the plant treated by ZnO NPs has no effect on the lipid parameters as well as the function of the kidney and liver of the rats that feed on this common bean. Zhu et al. (2020) indicated that the main route to cross the wheat leaf epidermis for ZnO NPs is via the stomata; then these nanoparticles accumulate and release Zn ions in the apoplast, and the released Zn ions and ZnO NPs are absorbed by mesophyll cells. Du et al. (2019) represented that the ZnO NPs were more significantly effective on the germination and growth of wheat rather than $ZnSO_4$. In addition, they showed that $ZnSO_4$ was more toxic than ZnO NPs at higher dosages. Applications of ZnO NPs are used as an antibacterial, antifungal, and anticancer drug delivery agent; as a biofertilizer in plant system; and as catalysts, (Husen and Iqbal 2019).

15.4.2 Iron (Fe)

It is absorbed by roots as Fe^{+2} and Fe^{+3}. The sufficiency range of Fe in plant tissue is between 50 and 250 ppm. Fe is a structural component of porphyrin molecules: cytochrome, heme protein, Fe-S protein, and leghaemoglobin. These substances are involved in oxidation-reduction reactions in respiration and photosynthesis. Fe is a catalyst to chlorophyll biosynthesis. It is a constituent of nitrogenase, the enzyme essential for N_2 fixation by N-fixing microorganisms (Dey et al. 2018). Fe is essential for chlorophyll development in cell, without iron photosynthesis it is not possible (Moinuddin et al. 2017). Fe nanoparticles have a potential role in plants as a fertilizer, as it can enhance photosynthesis efficiency and nutrient absorption (Rajabi et al. 2013; Rui et al. 2016; Tombuloglu et al. 2019).

Sheykhbaglou et al. (2010) and Dhoke et al. (2013) showed that iron containing nanoparticles have been used as nano-fertilizer for nutrition of plants. As an example, there was observed a positive effect of nano-FeO and nano-Zn-Cu-Fe oxide on the growth of mung (*Vigna radiata*) seedling, as well a positive influence on leaf and pod dry weight on soybean yield and quality. Azarpour et al. (2013) reported that nano iron fertilizers foliar spraying had significant effects at 1% probability level on fresh flower cover yield of saffron**.** Also, the foliar and root application of nanoparticles of Fe_2O_3 conduced to the increasing of root elongation of soybean and to the increase of photosynthetic parameters by foliar application (Alidoust and Isoda 2013). When using iron oxide NMs as a nano-fertilizer, Rui et al. 2016 performed a study on the effectiveness of Fe_2O_3 NPs as fertilizer for *Arachis hypogaea* has revealed that the Fe_2O_3 NPs and Fe_2O_3 -EDTA effectively increased the root length and plant height and biomass by regulating the phytohormones and antioxidant enzymes' activity. The Fe_2O_3 NPs were adsorbed onto the soil, increasing easy availability of iron to peanut plants. Likewise, growth parameters of *Solanum lycopersicum* were improved under the influence of Fe_2O_3 NPs (Shankramma et al. 2016). In addition, Sebastian et al. (2018) reported that iron oxide NPs with surface-fabricated phenolics from coconut husk could efficiently adsorb Ca and Cd. However, the interesting attribute of the study was the augmented iron accumulation in rice plants as well as tolerance towards calcium and cadmium stress. Increase of biomass and chlorophyll content attested the plant-growth accelerating action of the iron oxide NPs. Yuan et al. (2018) demonstrated a concentration specific role of Fe NPs in promoting growth in *Capsicum annuum* plants. The Fe NPs increased growth in these plants through reorganization of the leaf, increasing chloroplast per grana stacking, and regulating the vascular tissues within the leaf and stem.

15.4.3 Boron (B)

It plays an active role in protein synthesis during seed and cell wall formation. Boron also helps in water and nutrient transportation from root to shoot (Noaema and Barbara 2018). Boron metabolism and transport of carbohydrates, regulation of, meristematic tissue, cell wall synthesis, lignification growth regulator metabolism, phenol metabolism, integrity of membranes, root elongation, DNA synthesis, pollen formation, and pollination are the functiona of boron (Srivastava and Gupta 1996; Xu et al. 2000; Heckman 2007). In addition, Brown et al. (2002) indicated that boron plays a key role in higher plants by facilitating the short-and long-distance transport of sugar via the formation of borate-sugar complexes. In addition, boron may be of importance for maintaining the structural integrity of plasma plant cells membranes. This function is likely related to stabilization of cell membranes by boron association with some membrane constituents. Boron deficiency is often a problem in grape vines (*Vitis vinifera* L.) and in tree fruits, especially apple (*Malus sylvestris* Mill) and olive (*Olea europaea* L.). In field crops, it affects sunflowers (*Helianthus annuus* L.), sugar beet (*Beta vulgaris* L.), black gram (*Vigna mungo* L.), and oilseed rape (canola) (*Brassica napus* L.) (Rerkasem and Jamjod 2004).

15.4.4 Manganese (Mn)

It is associated with activation of enzymes like decarboxylase, dehydrogenase in photosynthesis (Moinuddin et al. 2017). Also, Mn related with photolysis of water in chloroplasts, regulation of enzyme activities, protection against oxidative damage of membranes (Srivastava and Gupta 1996; Xu et al. 2000; Heckman 2007). The application of Mn in concentration 0.05–1 mg/L on Mung bean roots in a Hoagland culture solution conduced to an increase in shoot and root length, dry and fresh biomass, and rootlet number (Pradhan et al. 2013). Dey et al. (2018) showed that plants absorb Mn^{+2} and low- molecular weight organically complexed Mn. Its concentration in plants typically ranges from 20 to 500 ppm. In Mn Functions, activates several important metabolic reactions, Aids in chlorophyll synthesis in photosynthesis because it is essential to electron transfer through chlorophyll to reduce CO_2 to carbohydrate and produce O_2 from H_2O, accelerates germination and maturity, it activates several enzymes that synthesize several amino acids and phenols important to lignin production and Increases availability of P and Ca. Shebl et al. (2019) said that the result showed that the spraying of manganese oxide nanoparticles on *Cucurbita pepo* plants led to the best vegetative growth characteristics, also, the characteristics of the fruits, yield, and the content of photosynthetic pigments.

15.4.5 Copper (Cu)

It is a constituent of several enzymes, with roles in photosynthesis, respiration, protein and carbohydrate metabolism, lignification, and pollen formation (Srivastava and Gupta 1996; Xu et al. 2000; Heckman 2007). Plants absorb Cu^{+2} and as a component of either natural or synthetic organic complexes. Normal Cu concentration in plant tissue ranges between 5 and 20 ppm. Functions: Lignin is a constituent in cell walls that imparts strength and rigidity, essential for erect stature of plants. Several enzymes (polyphenol oxidase and diamine oxidase) important to synthesis of lignin contain Cu. Copper is part of the enzyme cytochrome oxidase that catalyzes electron transfer in the transfer of electrons in respiration. It is important in carbohydrate and lipid metabolism (Dey et al. 2018). Copper nanoparticles play an important role as an antibacterial and antimicrobial agent in the formation of chlorophyll, enhancing porosity and taking part in some enzyme processes (Abbasifar et al. 2020).

Huo et al. (2014) found that mesoporous aluminosilicates have been noted to use as CuO nanoparticles carriers and thus have the potential for macro and micronutrients delivery to the soil Over the last several years**.** Guin et al. (2015) found the biologically synthesized CuO NPs to be significantly effective against oxidative stress and less toxic than the precursor material. Duman et al. (2016) reported that the antioxidant and DNA-cleavage properties of CuO NPs biosynthesized with the help of chamomile flower extract and act as a chemical nuclease, can generate DNA-cleavage, and may be useful for preventing cell proliferation.

15.4.6 Titanium (Ti)

Titanium dioxide nanoparticles ($nTiO_2$) are promising as efficient nutrient source for plants to improve biomass production due to enhanced nitrogen assimilation, photoreduction activities of photosystem II and electron transport chain, and scavenging of reactive oxygen species(Morteza et al. 2013; Raliya et al. 2015a, b). However, Zheng et al. (2005) revealed that increase in both germination rate and vigor indexes of aged spinach seeds were observed as a result of seed treatment with 0.25–4% of TiO_2NPs. Moreover, the developing chlorophyll, dry weight of plant, rate of photosynthesis, and the action of ribulose-bisphosphate carboxylase/oxygenase were essentially expanded. Also, Yang et al. (2006) demonstrated that nano-anatase TiO_2 treatment could improve the activities of numerous imperative enzymes including nitrate reductase, glutamine synthase, glutamate dehydrogenase, and glutamic-pyruvic transaminase. The effect of spinach roots exposure to TiO_2 nanoparticles present in soil conduced to an enhanced growth rate and chlorophyll as well as an enhanced rubisco activity and photosynthetic rate (Linglan et al. 2008). In addition, TiO_2 NPs due to their combined photo-catalytic and antimicrobial activity, whereas application of TiO_2 NPs reduced *P. cubensis* infection of cucumber by 91% and increase photosynthetic activity by 30% (Cui et al. 2009). Ahmad and

Rasool (2014) stated that TiO_2 nanomaterials application on different crops, e.g., wheat or soybean has increased the yield and reduced the pathogenic diseases, these effects being based on surface properties of TiO_2 nanoparticles as their photocatalytic characteristics. TiO_2 nanoparticles generally cause positive or non-consequential effects on plant growth for different food crops. For example, in hydroponic conditions, it was observed a significant increase in the root and shoot length of *Brassica juncea* seedling treated with TiO_2 nanoparticles (Garcia-Gomez and Fernandez 2019).

15.4.7 Silicon (Si)

Nano silicon dioxide developed the growth of the plant, net rate photosynthesis, level of transpiration, conductance of stomata, rate electron transport, and photochemical quell (Xie et al. 2011). However, Haghighi et al. (2012) and Siddiqui et al. (2014) showed that lower amounts of nano-SiO_2 increased germination of seeds in tomato, or of *Lycopersicum esculentum* seeds germination in concentration of 8 g L^{-1} nano-SiO_2 for a percentage of 22.16%. The same concentration increased the fresh weight of seedlings by 116.58% and seedlings dry weight by 117.46% compared to control, with an important action upon root and shoot growth. Nano-SiO_2 amplified various factors of the growth and conditions of seedlings, i.e., height, diameter of root collar, main length of roots, seedlings lateral root number as well as induction of chlorophyll synthesis under abiotic stress nano$SiO_{2.}$

15.5 Applications of Nano-Fertilization on Crops

Prasad et al. (2012) used seeds of *Arachis hypogea* to examine the influence of ZnO NPs on their growth and yield parameters. Various doses of ZnO NPs (25 nm) influenced the overall plant-growth response in terms of seed germination, seedling vigor index, root growth, flowering, chlorophyll content, and pod yield. Amirnia et al. (2014) conducted a study of the effect of nano-fertilizers application and maternal corm weight on flowering of some saffron (*Crocus sativus* L.) ecotypes, in Iran. Significant differences between nano-fertilizers levels, saffron ecotypes, maternal corm weight and their interactions in terms of all flowering traits highlighted the importance of the nano-fertilizers on improving saffron yield. In addition, it was also clear that Fe, P, and K nano-fertilizers all had positive effects on the saffron flowering. In this regard, Abdel-Aziz et al. (2016), showed that the foliar application of either normal or nano-fertilizer at different concentrations to wheat plants, induced marked significant variable increases in all growth variables determined at fully vegetative and reproductive growth stages.

To evaluate the effects of foliar spray of micronutrient nano-fertilizer (iron and zinc) and nano-titanium dioxide ($nTiO_2$) solution on grain yield and its components in barley under supplemental irrigation conditions, a field experiment was carried out by Janmohammadi et al. (2016) in the semi-arid highland region of Maragheh, Iran.

A considerable improvement was observed in grain mass, spike length, number of the grains per spike, chlorophyll content, grain yield, and harvest index by application of nano-fertilizer. Foliar application of $nTiO_2$ positively affected some morphophysiological characteristics like as days to anthesis, chlorophyll content, and straw yield.

Aghajani and Soleymani (2017) found that nano fertilization types including (nano Biologic and nano Zn-Fe-Mn) resulted in the highest rate of yield and yield components for bean under water sufficient and deficient conditions. Also, Sabaghnia et al. (2017) performed to study the effects of farmyard manure and nano-fertilizers (Mn, Fe, and Zn) on sunflower. The results of this investigation showed that application of nanoparticles may alleviate the adverse environmental factors and improve the sunflower performance and the integrated application of organic manure and nano-micronutrients is more effective.

Jahan (2018) conducted a field experiment to study the influence of using nano fertilization on growth, physiology, and yield parameters of okra. Nano-fertilizer significantly increased growth and physiological parameters such as leaf numbers, the plant height, chlorophyll content, Chl fluorescences, yield, net photosynthesis rate, photo synthetically active radiation, and relative water content. Moreover, nano-fertilizers significantly increased yield parameters of okra production. Abdelkader et al. (2019) conducted a study that was carried out to evaluate the effect of different phosphorus fertilization rates as P_2O_5, nano-micronutrients concentrations (Fe, Zn, B, Mn, Cu, and Mo) as well as their combinations on growth and production of fennel (*Foeniculum vulgare*, L.). The results showed the importance of the nano-micronutrients on improving fennel growth, fruits, and volatile oil yield compared to control. In general, 45 kg P_2O_5/feddan +500 or 1000 mg/L of nano-micronutrients as foliar spray had significant effects in above-mentioned parameters of fennel plant. Merghany et al. (2019) conducted an experiment to determine the effects of liquid nano-fertilizer on cucumber growth, production and quality of cucumber. The results stated that the nano-fertilizer treatments significantly improved the growth and yield of cucumber compared with control treatment. All treatments of nano-fertilizer led to increase plant height, number of leaves / plants, chlorophyll content, yield, and NPK % in leaves and fruits. It can be concluded that nano-fertilizer improved the plant growth, yield, and fruit quality of cucumber and it can be used as an alternative to mineral fertilizers.

Sajyan et al. (2019) studied that, the effect of nano-fertilizer on vegetative and reproductive growth of salt-stressed tomato plants. Nano-fertilizer increased leaf number and stem diameter in salt-stressed plants regardless of the application dose. Flowering characteristics were also improved by nano-fertilizer application under all salinity levels. Consequently, salt tolerance of tomato was ameliorated by nano-fertilizer application.

Shebl et al. (2019) conducted a field experiment to study the influence of nano-fertilizers on *Cucurbita pepo* L. The result indicated that nano-fertilizers improved the growth and the yield in comparison with untreated plants. Furthermore, the yield of fruit squash was significantly affected with Mn nano-oxide especially when it is used individually or combined with Fe nano-oxide. Also, the content of organic matter, protein, lipids, and energy recorded the higher levels in fruits of squash plants that have been sprayed with Fe nano-oxide.

Ghasemi et al. (2020) investigated the effect of nano-fertilizers (n) on the yield components and antioxidant properties of Dragon's head Balangu (*Lallemantia* sp.), the results indicated that the combination of winter cultivation and NPK-n + Fe-chelated-n fertilizers is the most appropriate treatment to acquire highest qualitative and quantitative yield of Dragon's head. An experiment was undertaken in order to assess the performance of new commercial nano-based water-soluble (Nano- Max NPK foliar spray) foliar fertilizer in comparison to commonly adopted water-soluble foliar fertilizer. Results revealed that the treatment as regards average tomato fruit weight (Panda et al. 2020). Tarafder et al. (2020) indicated that the composition of the proposed hybrid nano-fertilizer was functionally valuable for slow and sustainable release of plant nutrients. The obtained result showed a significant increase of Cu^{2+}, Fe^{2+}, and Zn^{2+} nutrient uptake in *A. esculentus* as a result of slow release from hybrid nano-fertilizer, whereas the slow releasing of hybrid nano-fertilizer is observed during leaching studies and confirmed the availability of Ca^{2+}, PO_4^{3-}, NO_2^-, NO_3^-, Cu^{2+}, Fe^{2+}, and Zn^{2+}.

15.6 Nano-Applications Microelements Fertilizing on Sugar Beet

Nano-fertilizer application promoted the growth, development, yield, and quality traits of sugar beet and has the potential to improve crop production and plant nutrition. These conclusions have been reported by several authors, e.g., Abd El-Hadi et al. (2002), Ramadan and Nassar (2004), Nemeat-Alla and Mohamed (2005), Nemeat-Alla et al. (2009), Moustafa et al. (2011), Amin et al. (2013), Asadzade et al. (2015), Mekdad and Rady (2016), Dewdar et al. (2018), Abbas et al. (2020). However, Liu and Lal (2015) reported that the application of nano particles to sugar beet plants can be beneficial for growth and development due to its ability for greater absorbance and high reactivity.

In western Poland, Barłóg et al. (2015) conducted an experiment to study the effect of zinc band application on sugar beet yield, quality, and nutrient uptake. The significant root and sugar yield increase compared to the control was recorded at a level of 0.5–2.0 Zn kg/ha, the best quality of taproots reflected in biological sugar content was observed at a level of 0.5 kg/ha. Also, Masri and Hamza (2015) conducted an experiment to study the influence of foliar application with micronutrients (zinc (Zn) + Manganese (Mn) + Iron (Fe) + Boron (B)) on productivity of sugar beet. The increasing micronutrients mixture significantly increased root weight, root yield, sugar yield, and quality traits, in terms of total soluble solids (TSS), sucrose%, purity%, and extractable sucrose% were significantly increased by increasing levels of micronutrients. However, Rassam et al. (2015) conducted a field experiment to investigate the effect of foliar application of micronutrients on quality and quantity of sugar beet. The foliar spraying of micronutrients significantly increased root yield, content of sucrose, and refined sugar compared to the control.

Hassnein et al. (2019) recommended that using nano-nitrogen fertilizer (Sissay) and micronutrients (B, Zn, and Mn) with mineral nitrogen fertilizer can save 40% from recommended dose of mineral nitrogen fertilizer without insignificant differences in root and sugar yield per plant of sugar beet plants. Furthermore, El-Sherief et al. (2016) conducted an experiment to study the effect both individual and combined applications of B, Zn, and Mn on juice quality and the content of some macro- and micronutrients of sugar beet. All micronutrients at all levels had significant effect on roots and sucrose yields in sugar beet juice at harvest, also, B, Zn, Mn, and their mixture at the highest levels significantly increased roots and sucrose yields. In context, Dewdar et al. (2018) and Abbas et al. (2020) conducted a field experiment to study the influence of foliar spraying nano-micronutrients (Fe, Mn, Zn, and B) on yield and quality of sugar beet. The findings of the study exhibited that the best results were sugar beet plants treated with nano-microelements 200 mg/L + urea 1% could be ranked as the first favorable treatment, this treatment significantly produced the highest yields with improved quality traits of sugar beet and results in saving the plants' needs from micronutrient and nitrogen fertilizer. Moreover, nano-fertilizers have great impact on the soil, can reduce the toxicity of the soil, and decrease the frequency of fertilizer application. The foliar application of Fe, Mn, and Zn mixture was assessed to improve growth and yields and their qualities in two multigerm cultivars of *Beta vulgaris* L. (Mekdad and Rady 2016).

Qotob et al. (2020) reported that the application of nanotechnology in agriculture as using nano-boron increased the application efficiency, decreased pollution and risk of fertilizers used, and increased sugar beet quality. Increasing nano-boron level under different growth stages increased sugar and white sugar contents, on contrary impurities (Na, K, and α-amino-N) loss and molasses sugar percentage were decreased (Pirzad et al. 2019). Also, Rahimi et al. (2016) indicated that micronutrients (Fe, Zn, B, and Mn) enhanced sugar percentage, amount of K, Na, N, alkalinity, crystallized sugar percentage, sugar yield, and percentage of sugar in molasses.

Matsi et al. (2005) have done a survey conducted in order to estimate micronutrient levels (Cu, Zn, Fe, and Mn) in sugar beet plants and soils. Concentrations of DTPA-extractable Fe and Mn, and plant Zn and Mn, were significantly and negatively correlated with soil pH. Soil pH and DTPA-extractable Fe seemed to have a significant positive impact on root, top, and raw sugar yields. However, in all cases, less than 14% of the variance of the sugar beet parameters was explained by soil characteristics. However, Jakienė et al. (2015) performed an experiment to study the effect of the bio-organic nano-fertilizer on improving sugar beet photosynthesis process and productivity. The results indicated that a single application of the bio-organic fertilizer increased the number of leaves, leaf area, root diameter, canopy dry biomass, root biomass, net photosynthetic productivity, root yield, sucrose content and yield of white sugar in comparison with the control treatment.

15.7 Future Prospects

More efforts are required to investigate the nano-micronutrients application on sugar beet (*Beta vulgaris* L.) under different environmental conditions as well as to apply of nano-micronutrients fertilizations on productivity and quality traits of sugar beet under biotic and abiotic stresses.

15.8 Conclusions

The deficiency of soil nutrients such as micronutrients has been known as the major limitations in beet crop production. Nano-micronutrients application promoted the growth, development, yield, and quality traits of different crops and has the potential to improve crop production and plant nutrition. Nano-fertilizers can be used as an alternative to mineral fertilizers due to the nano-micronutrients facilitating increased nutrient utilization efficiency. The foliar application of nano-zinc (Zn), Manganese (Mn), Iron (Fe), and Boron (B) has an important role to improve growth and yield and quality traits of sugar beet (*Beta vulgaris* L.). Nano-fertilizations can gradually provide crops with their essential nutrients and can be of environmental and economic significance in comparison to the chemical fertilization.

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