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Roles of Nano-Fertilizers in Sustainable Agriculture and Biosafety

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ABSTRACT

Nano technology is a new novel approach to enhance agricultural production with improved quality, biological support, financial stability and environmental safety. Eco-friendly technology is rising progressively important in the present modern agriculture as alternatives to chemical pesticides and traditional fertilizers. Nano technology offers a solution to overcome the limitations of conventional agriculture. Therefore, recent developments in agriculture using nano-particles (NPs) should be well examined. This review presented a overview about biosynthesis of NPs, NPs as nano-fertilizers and pesticides, its application in agriculture. We also showed recent studies of NPs-plant interactions, fate and safety of nano-particles in plants and alleviating the harmful effects of abiotic stresses. The nano-fertilizers are essential to minimize the use of inorganic chemical fertilizers and reduce the antagonistic effects on environment. Nano-fertilizers are more reactive which can penetrate through epidermis allowing for controlled release and targeted distribution and thus decreasing nutrients surplus while enhancing the nutrient use efficiency. We concluded that these NPs are very crucial in alleviating abiotic stresses and heavy metal toxicity. Nevertheless, some studies reported that NPs showed some toxic effects on higher plants by inducing oxidative stress signals. The knowledge in this review article is critical in defining disadvantages and future perspectives of nano-fertilizers as an alternative to conventional fertilizers.

Keywords Nano-fertilizers, Foliar spray, Nutrient use efficiency, Environment.

INTRODUCTION

Nano-particles (NPs) are tiny molecules (size ranged from 1–100 nm) having different physico-chemical properties than other bulk materials (Reda *et al*. 2021). Nano-fertilizers provide the nutrients in nano form which helps in enhancing growth and production of crops (Dimkpa and Bindraban 2016). Based on the needs of plants, the nano-fertilizers can be categories

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into three sections namely, macro nano-fertilizers, micro nano-fertilizers and nano-particulate fertilizers (Chhipa and Joshi 2016). These particles can be spread like a powder form or a liquid with diameter less than 100 nm (Josef and Katarína 2015). They provide the nutrients in available form to plants, thus increasing nutrient uptake and boost the production. The important features of nano-fertilizers can be briefed as (1) appropriate deliver of nutrients for enhancing crop growth through soil and foliar applications, (2) they are cost effective and sustainable sources of nutrients for plants and (3) play a key role in mitigating environmental pollution (Guru *et al*. 2015). India being a developing and agricultural country, urges the need of simple, cost effective and efficient technology to enhance the crop establishment under various environmental conditions. Different types of techniques can be used to improve crop growth and yield of which, priming of seed is the most simple and suitable one to synchronise germination, enhance emergence and crop establishment in the field (Ghassemi *et al*. 2017). The review aimed to present the methods of nano-particles synthesis, its role and importance of NPs as nano-fertilizers and their impact on plant and soil quality as well as the interaction between nano-particles and plants.

Fabrication of nano-fertilizers

Due to the rising needs and demand for environmentally friendly, effective and non-toxic synthesis of nano-material technology, biofabrication of NPs using the biological methods has got great attention (Abd-El-Hack *et al*. 2021). Proteins, enzymes, phenolic compounds, pigments, alkaloids and amines are the major molecules responsible for synthesis of NPs' in plants and microorganisms (Hassanin *et al*. 2020). The physical methods are costly while chemical methods use toxic solvents which can affect the environment.

Nano-fertilizers as nano-priming

Nano-priming has proved to more promising than other traditional priming techniques for achieving agricultural yields feasibly (Abbasi *et al*. 2021). This technique of priming use nano-particles (NPs) with size less than 100 nm and the term "priming" relates to development of stress tolerance (Chandrasekaran *et al*. 2020). Different types of nano-priming are displayed in Fig. 1. It is reported that germination of seed and seedling vigour are induced potentially in various crops upon nano-priming (Zhu *et al*. 2019).

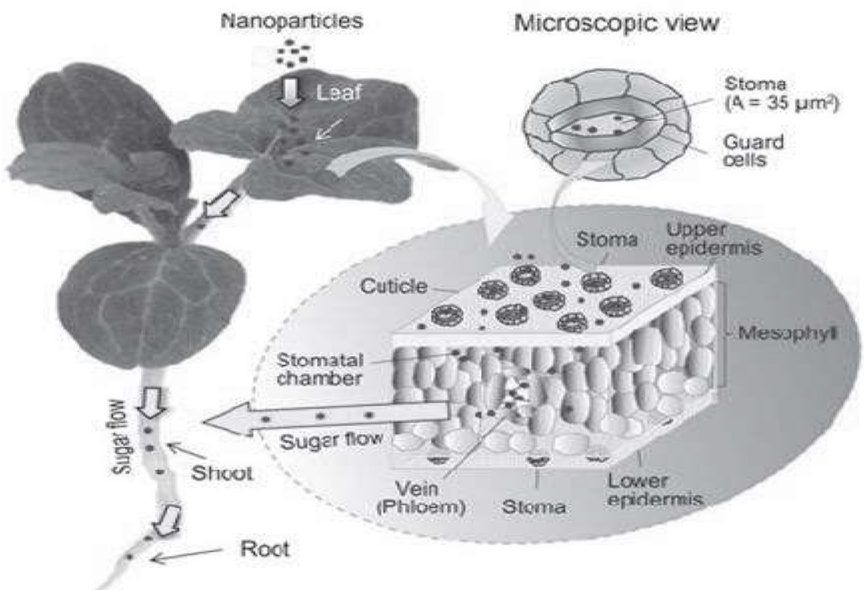

Fig. 1. Mode of entry of NPs through foliar spray.

The induction of secondary metabolism to offset adverse environmental stresses in plants results in synthesis of several secondary metabolites such as alkaloids, phenylpropanoids, sulfur-compounds and terpenoids. In addition, they have also been utilized as bioactive compounds (antimicrobials, antioxidants, anticancer) and protect against various diseases (Seca *et al*. 2018).

Role of nano-fertilizers as a foliar spray

The application of nutrients traditional to soil has several drawbacks regarding nutrient availability to plants. Hence, foliar application of nutrients is the most efficient method for correcting nutrient deficiencies and enhancing crop yield and quality. In addition, they also reduces environmental pollution and increase nutrient use efficiency via reducing the quantity of fertilizer applied to soil. Even though plant leaves allow gaseous exchange but cuticle restricts the penetration of substances (Schwab *et al*. 2015). Nano-fertilizers have large surface area, absorption capacity and controlled-release to targeted sites have been considered as a smart delivery system (Rameshaiah *et al*. 2015). Therefore, it is appropriate to present the relevant studies of nano-fertilizer penetration, translocation through leaves, their impact on crop production and yield and plant tolerance to abiotic stress. Mode of entry of NPs through foliar spray is depicted in Fig. 1.

Effect of foliar feeding of nano-fertilizers on growth parameters of plants

Growth

Nano-fertilizers have an important role in physiological and biochemical processes by increasing nutrient availability, which enhances metabolic processes thus promoting meristematic activities thereby higher apical growth as well as photosynthetic leaf area. It is documented by researchers, that foliar spray of nano-formulations of NPK and micronutrients mixture increased plant height and number of branches in black gram (Marimuthu and Surendran 2015). It was also observed that nano NPK increased leave growth in wheat which was due to enhanced nutrient availability and easy penetration of nano formulation through stomata via gas uptake. Foliar applied nano-fertilizer (nitrogen) increased leaf dry weight in peppermint by 165% than control (Abdel-Aziz *et al*. 2018).

Physiological parameters

Foliar application of nano-TiO2 has recorded significantly higher carotenoids, chlorophyll content and anthocyanins in maize, which facilitated an increase in yield (Morteza *et al*. 2013). It is also found that application of nano-sized TiO2 as foliar spray positively influenced morphophysiological characters such as days to anthesis of barley (Janmohammadi *et al*. 2016). In fact, nTiO2 improved chlorophyll structure and helps better in sunlight capturing, facilitates manufacture of chlorophyll pigments, stimulates RUBISCO enzyme activity and photosynthesis. Nano TiO2 can improve spinach growth and also increased nitrogen metabolism, chlorophyll and protein contents.

Yield

Nowadays, researchers are trying to examine the nano-fertilizers potential to increase the crop yield. Foliar applications had reflected in improving yield parameters of wheat (Abdel-Aziz *et al*. 2018b). Foliar spray of NPK nano-fertilizers in chickpea increased yield and yield components due to increased growth hormone activities and rapid enhancement of metabolic processes, tended to increase flowering and grain filling. Application of nano-fertilizers have a great role in increasing cotton yield besides reducing the fertilizer cost thereby minimizing the environmental pollution. In addition, foliar application of nano iron, zinc and NPK stimulates growth of chickpea which results in enhanced yield and yield components (Drostkar *et al*. 2016).

Role of nano-fertilizers to nutrient flow

Major portion of inorganic fertilizers applied to soil are lost which become unavailable for plant uptake. More specifically, 40–70% of nitrogen, 80–90%, phosphorus and 50–90% of potassium fertilizers are fixed and/or lost in soils which results in loss of economic. Therefore, more fertilizers added to soils (Fig.

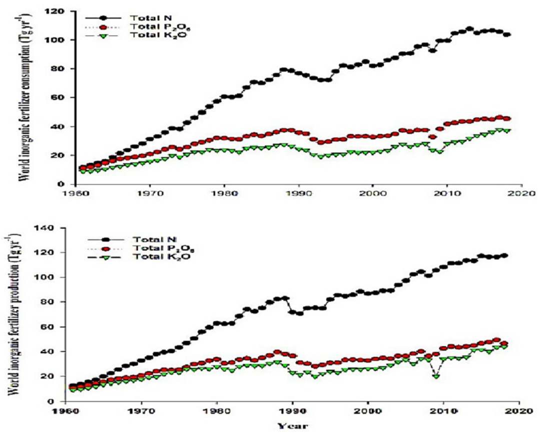

Fig. 2. Changes in pattern of inorganic fertilizers production and consumption.

2) to compensate the fertilizers lost, again affects the soil nutrient balance. Nano membranes could be used as a fertilizer coating to facilitate slow release of supplements. To combat the issue of overusing inorganic fertilizer, nano-fertilizers being slow released can be used. Because of its slow rate of discharging, these slowly released nano-nutrients may be an alternative to dissolve inorganic fertilizers. Thus, plants would absorb majority of their nutrient requirements (Huiyuan *et al*. 2018). Moreover, nano-materials make fertilizer particles stronger because higher surface tension than traditional fertilizers, increasing the efficacy in controlling nutrient release. Changes in pattern of inorganic fertilizers production and consumption are displayed in Fig. 2.

Nano-materials enhance nutrient activity

Bioactive substances coated with nano-particles

Nano-encapsulations provide stability to bioactive substances which would otherwise susceptible heat, UV and oxidation. Nano-encapsulation is a new nano-technology that allows the active ingredients to be released from capsules in controlled manner gradually (Saifullah *et al*. 2019). It is somewhat similar to microencapsulation, except the particles are nano size. Different mechanisms such as diffusion, dissolution or biodegradation may be used to deliver these bioactive compounds in nano-encapsulated substances.

Nano-micronutrients

Micronutrients such as zinc, silica, copper and iron has been synthesized at nano-scale and used in plant growth improvement. Nano Fe plant growth-promoting rhizobacteria (PGPR) on maize found that foliar spray of *Azospirillum brasilens* and nano Fe improved plant growth and yield (Heidari *et al*. 2018). PGPR (arbuscular mycorrhizal) inoculated plants with low dose of Fe-NPs increased phytoremediation of heavy metal significantly, improvied root zone and leaf of young plants (Mokarram *et al*. 2019). Additionally, the addition of nano Zn-Fe oxide and bioagents and to salt-stressed wheat plants improved seed development significantly, photosynthesis as well as osmolyte content, i.e., soluble sugars, proline and antioxidants (Babaei *et al*. 2017).

Mechanisms and mode of entry of nps in plants

The plasma membrane in leaves of plants has a phospholipid bilayer of which hydrophilic head and hydrophobic tails act as a barrier for transfer of molecules through it (Fig. 3). This entry into plant cells was propounded by three mechanisms (Behzadi *et al*. 2017). In the first mechanism, as NPs are small in sizes can easily cross plasma membrane by a process called direct diffusion. The passage is associated with numerous features in palnts such as size, constitution, hydrophobicity, shape and charge of the particles (Auria *et al*. 2019). In second mechanism, NPs are transported into the cell actively by engulfing the cell membrane, a process known as endocytosis (Foroozandeh *et al*. 2018). The third mechanism is through transmembrane proteins that regulate movement of NPs into cells (Li *et al*. 2020). Nevertheless, it is limited by some factors namely high degree of specificity, least open possibility and size of small pores. The mode of transport from plant cell to tissues is by foliar/shoots or roots. This is mediated either by an apoplastic or symplastic mode of transport (Perez-de-Luque 2017). Contrarily, foliar application of NPs in plants is translocated through phloem and accumulates in organs (Su *et al*. 2019). Apoplastic transport occurs in outer plasma membrane via xylem vessels, extracellular matrix and cell walls of adjacent cells. It allows NPs to move vascular tissue and root cylinder radially and thereafter ascends to above-

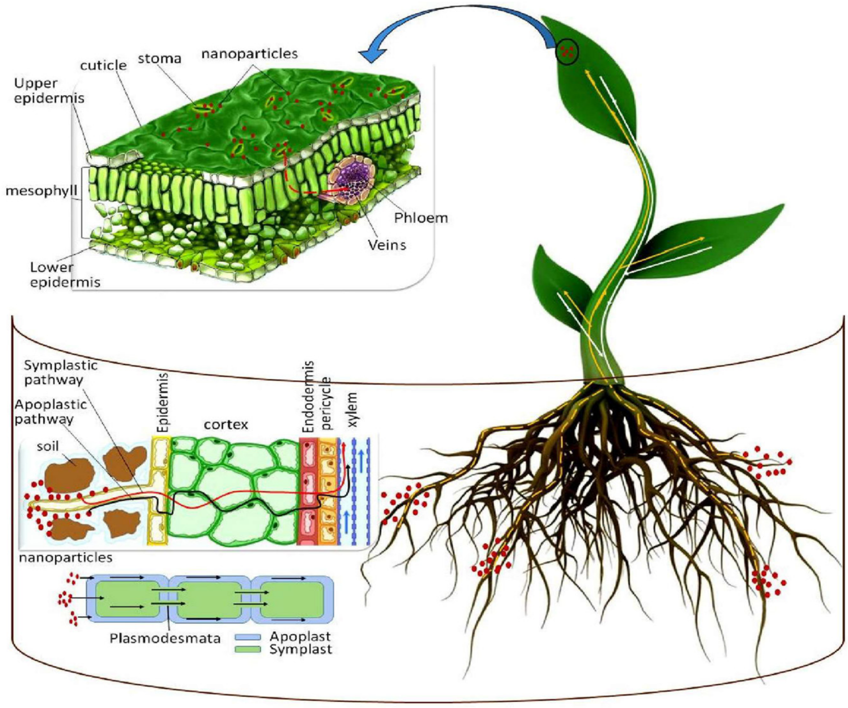

Fig. 3. Mode of entry of NPs into plants.

ground parts of plant (Sun *et al*. 2014). NPs can also be transported into plants by forming complexes with membrane transporters. Nano-materials have the ability to enter leaf stomata from the atmosphere and then redistribute to plant parts. It is observed that calcium oxide NPs (n-CaO) get transported through phloem tissue (Deepa *et al*. 2015).

Alleviation of abiotic stress

Abiotic stresses such as drought, salinity, heavy metals, chilling, freezing, flooding, heat and ultra-violet radiation. Among these stresses drought and salinity represents great threat to crop production globally. These abiotic stresses may cause great loss in production of about 50%. Salinity causes imbalance of nutrients, membrane damage and inhibition of enzymatic activites in plants by osmotic and ionic stress (Hasanuzzaman *et al*. 2013). In addition, soil salinity interferes with water availability negatively to plants, absorption of nutrients and crop yield and quality. Therefore, use the nano-materials in alleviating these harmful abiotic stresses are one of the important approaches.

The applications of nano-particles in agriculture and its safety

The nano-particles have tremendous potential to use in a variety of areas such as agriculture, horticulture, pharmaceuticals, however, the risks of these materials pose threat to humans and environment remain still unknown. The term “nano toxicology” is used not only to discuss the harmful effects, but also a safe strategy of using these products. The nano-particles toxicological properties must be limited to specific item at specific period. To determine NPs residues in the environment and/or to be exposed to biological system, it is very much essential to determine the toxicological data for nano-products. Although there is no clear evidence of NPs that cause human disease, some studies have been suggested they trigger biological responses which lead to toxicological problems, such as cell inflammatory and genotoxic effects in DNA (Haji *et al*. 2016). On the other hand, these nano products showed more notable effects in the improvement of plant such as protection of environment, financial stability as well as biological sustainability. Until the nano-fertilizer is placed in market, its impact on environmental and public health must be assessed and reduced through regulation and re-design of that product. However, the behavior and toxicity depends on size, dosage, fabrication materials. When nano-materials used in higher concentration plants have adverse effects while lower doses provide beneficial effects if applied at appropriate condition. The applications at high concentrations (>500 mg/ L) are phytotoxic whereas, at lower concentrations (50 mg/L) showed beneficial effect (Reddy *et al*. 2016). Chemically derived NPs can have toxic effect when interact with other media and produce hazardous compounds as by products (Jaison *et al*. 2018). The US Food and Drug Administration (FDA) considered this adverse effects of NPs and concluded for human use they are neither safe nor harmful.

Future prospects of nano-fertilizers

The toxicity of newly developed NPs depends on, size of NP (smaller the size more the toxic as higher specific area), seed size (small seeds are more sensitive), plant species and ability to adsorb NPs on seed surface. Hence, there is need of extending new research area to find the appropriate NPs along with their concentrations and their effect on specific crops. In addition, research needs to be done how to be avoiding the use of herbicides that not only acts against weeds but also affects the crop growth. Will nano-particles able to solve this problem? Nowadays, there are many environmental issues such as urbanization, climate change, which has severely impacted in agriculture. In this condition, lies a scope where the nano technology approaches can be a boon.

CONCLUSION

The invention of nano-materials is a technological breakthrough in designing material and development. Use of nano technology in agriculture is still in its young stage. However, it has the potential to transform new agricultural systems, especially when it comes to issues of fertilizer application. Nano-fertilizers has exceptional impact on production of crops by reducing costs and emission risks of fertilizers. Nano-fertilizers are more reactive, soluble and increase penetration through cuticle that allows targeted delivery. Crop growth, yield and quality and nutrient use efficiency are improved by application of nano-fertilizers that reduce abiotic stresses and toxicity of heavy metal.

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