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Nanofertilizers for efficient fruit production: A review

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Abstract
Fruit crops are high nutrient feeders, as a result, for optimum growth and production, a better nutrition management plan is essential. Thus, nutrient management is the essential component of fruit production. Nanofertilizers are effective technology for increasing nutrient use efficiency in fruit crops. Nanofertilizers are nanomaterials with sizes ranging from 1 to 100 nm that provide at least one type of nutrient to plants. Nanoparticles are categorized as macro-nanofertilizers, micronanofertilizers, nano-bio fertilizers, nanoparticulate fertilizers, and nanocoatings or packaging materials based on plant nutritional requirements. Nano-fertilizers outperform even modern conventional fertilizers in terms of effectiveness due to their high surface area to volume ratio. The plant nutrients encapsulated in nanoparticles also boost nutrient availability and, consequently, crop plant nutrient uptake. When very low quantities of nanofertilizers are sprayed on fruit trees, these compounds have a significant influence by enhancing the growth, yield, quality, and leaf nutrient content of these fruit crops. Nanofertilizers also help the plants to tolerate different biotic stresses.

Keywords: Nanofertilizers, nanoparticles, fruit crops, fruit yield, nutrient uptake, nutrient use efficiency

Introduction

Agriculture, including horticulture, is the major sector in India economy. The agricultural sector in India accounts for 18% of the country's GDP and employs 50% of the workforce. India is the second largest producer of fruits and vegetable in world after China. The varied climate of India refers to the availability of a wide range of fresh fruits and vegetables. According to the National Horticulture Database released by the National Horticulture Board, India produced 99.07 million metric tonnes of fruits and 191.77 million metric tonnes of vegetables in 2019-20. Fruit cultivation covered 6.66 million hectares, while vegetable cultivation covered 10.35 million hectares. According to FAO (2019), India stands first in banana production (26.08%), papaya production (44.05%), and mango production (45.89%).

Despite having second rank in fruit production in the world, India lags behind in the productivity of fruits in the world. There are several reasons for low productivity of fruits in India such as population pressure, uneconomic holdings, decline in soil fertility, etc. As the population of world is increasing, the demand of fruits is also increasing in the world. To meet this demand, farmers have relied heavily on fertilizers and insecticides, genetically engineered crops, insect pests, and disease-resistant cultivars for the last five decades (Yadav *et al.*, 2013). Fertilizers have been critical in increasing the production of agricultural crops in general, and fruits in particular. However, when utilized in excess, these chemical fertilizers have harmed both fruit quality and soil health (Bai *et al.*, 2020) [7].

As in any other crops, growth, development, productivity and quality of fruit crops are also highly influenced by nutrient supply. Nutrient management is a very important aspect in fruit production. Fruit plants require supply of 16 essential nutrients for proper growth and development. Fruit crops are heavy nutrient feeders, thus proper growth and production necessitate a good nutrition management approach (Kumari *et al.*, 2020) [20]. The requirement of nutrients varies from crop to crop, species to species, variety to variety, climatic conditions, growing medium, soil types and availability of nutrients (Benton, 2012) [8]. Approximately 25 to 30% of supplied nutrients are absorbed by fruit crops throughout growth and development, while the remainder is lost through mineralization, leaching, and bioconversions (Bollag *et al.*, 1992) [9]. To overcome this problems, several new and efficient strategies have been utilized to increase the nutrient use efficiencies, such as integrated nutrient management, fertigation, precision fertilization, split applications and use of nanofertilizers (Chippa, 2017) [10]. This article describes the current state of knowledge and application of nanofertilizers for the efficient growth, productivity, and quality of fruit crops.

Nanofertilizers

Nanofertilizers are nanomaterial with sizes ranging from 1 to 100 nm that provide at least one type of nutrient to plants (Singh, 2017) [38]. These have a large surface area, a high absorption capacity, and a smooth delivery system that allows for regulated release kinetics to active areas (Chhipa and Joshi, 2016) [11]. Nanoparticles are categorized as macro-nanofertilizers, micro-nanofertilizers, nano-biofertilizers, nanoparticulate fertilizers, and nanocoatings or packaging materials based on plant nutritional requirements.

Carbon nanotubes, manganese, copper, zinc, molybdenum, silicon, iron, their oxides, and nanoformulations of commercially used agricultural inputs such as urea, potassium, phosphorus, and sulphur are examples of nanotechnological materials (Taha *et al.*, 2016; Alshaal and Ramady, 2017) [40, 4]. Nanofertilizers are applied to the plants by means of soil application, foliar application, injection to the plants and in vitro methods. Foliar nutrient application has been shown to be a rapid technique to correct nutrient deficits and improve crop productivity (Roemheld, 1999) [44]. Nanofertilizer treatments have been demonstrated to minimize abiotic stresses and increase crop nutrient absorption under adverse climatic conditions (Abou El-nour *et al.*, 2010) [3]. Nanoparticles have the potential to be a viable tool as an alternate source of nutrients and packaging that improves fruit growth, productivity, quality, and shelf life (Chowdhury *et al.*, 2017; Kaphle *et al.*, 2018) [12, 19].

Nanomaterials or nanoparticles for nanofertilizers can be manufactured using one of three techniques: top down, bottom up, or biological. In top down approach, nanoparticles are created from their macro-scale counterparts by the means of milling, while in bottom up approach, nanoscale materials are created from atoms and molecules with the help of chemical reactions. In biological approach, nanomaterials are synthesized biologically with the help of plants, fungi, bacteria, etc.

Effect of nanofertilizers on the growth and flowering of fruit crops

Nanofertilizers enhance the growth and flowering of the fruit crops than the traditional fertilizers, but there is very little research on their impact on fruit crop flowering. Foliar spraying on *Citrus Aurantifolia* saplings with the Nano Optimus Plus fertilizer and chelated potassium separately or in combination resulted in a significant boost in vegetative growth parameters (Amin *et al.*, 2020) [5]. In Flame Seedless grapevines, soil application of 30 g N/vine with 0.6% carbon nano-tubes (CNTs) from total nitrogen significantly increased leaf area, leaf fresh weight and leaf dry weight, shoot length, shoot diameter and number of leaves per shoot of grapevines (Abdel-Hak *et al.*, 2018) [2]. Abdelaziz *et al.* (2019) [1] recorded significantly higher shoot length, shoot thickness, leaf area and number of leaves per shoot in mango cv. Keitte, when sprayed with nano-boron at 5 to 20 ppm three times than normal boron at 50 to 200 ppm. With increase in concentration of nano boron, such growth attributes were gradually promoted. Soil application of 200 g of Nano-powder potassium sulfate per vine significantly increased the leaf area, internode length and internode thickness of grape cv. Crimson Seedless than normal potassium sulfate (Shalan, 2020) [34]. Nanofertilizers have a large surface due to their small particle size, which increases their solubility in many solvents, particularly water. This property aids in the penetration of nanoparticles into contact surfaces like as roots and leaves. Nano-fertilizers improve the rate of photosynthesis in the plant, resulting in an increase in dry matter production and carbohydrates and so increasing plant vegetative development in general (Qureshi *et al.*, 2018) [26]. Spraying of mango trees with nano-chitosan @ 5 ml/L resulted in higher number of flower panicles with reduction in mango malformation incidence (Zagzog *et al.*, 2017) [42]. The foliar application of nanosize calcite and seaweed extract increase the flower quality, pollen germination percentage and pollen viability of grape vines (Sabir, 2015) [30].

Effect on nanofertilizers on the yield and quality of fruit crops

The soil and foliar application of nanofertilizers as macro- or micronutrients increases fruit crop yield, improves fruit quality, and extends fruit shelf life. Over traditional fertilizer urea, foliar application of nano-N @ 0.50 g N/L significantly enhanced the number of fruits per tree, fruit yield, fruit weight, and aril percentage of *Punica granatum* cv. Ardestani (Davarpanah *et al.*, 2017) [14]. In Zaghloul date palm, foliar application of Nano. NPK @ 1000:500:500 g/palm resulted significantly higher fruit yield, bunch weight, total soluble solids, total sugars and pulp percentage than conventional fertilizers (Roshdy and Refaai, 2016) [29]. Combine application of nano super @ l g and NPK @ 1 g/L on leaves of date palm cv. Hillawi significantly improved fruit weight, bunch weight, fruit ripening, dry matter and total soluble solids (Shareef *et al.*, 2020) [36]. El-Hak *et al.* (2019) [16] recorded higher number of clusters, cluster weight, fruit yield, juice percentage, total soluble solids and anthocyanin content in Flame Seedless grapes with foliar application of Nano-zinc @ 1.2 ppm. Cluster weight, cluster length, cluster width, berry weight, soluble solids content, SSC: acid ratio and anthocyanin content of Crimson Seedless grapes was significantly increased by soil application of 200 g of nano-powder potassium sulfate per vine in comparison with normal potassium sulfate powder (Shalan, 2020) [34]. The fruit yield and fruit quality of pomegranate cultivars was significantly improved by foliar application of Nano-Zn @ 60 ppm + Nano-B @ 6.5 ppm (Davarpanah *et al.*, 2016) [13]; Nano-Se @ 2 µM (Zahedi *et al.*, 2019) [43] and Nano $FeSO_4$ @ 144 ppm (Davarpanah *et al.*, 2020) [15]. In mango, fruit yield and fruit quality was improved by foliar application of Nano zinc @ 1 g/L (Zagzog *et al.*, 2017) [42]; Nano NPKMg @ 0.4% (Saied, 2018) and Nano boron @ 20 ppm (Abdelaziz *et al.*, 2019) [1].

Nanotechnology could be one of the research topics that can improve postharvest life and reduce crop losses in fruit crops (Davarpanah *et al.*, 2016; 2017) [13, 14]. Nanomaterials work on three levels to slow the senescence process: regulating respiration, decreased water evaporation of the fruit and restriction in microbe activity, which can be accomplished by regulating the environment at a constant relative humidity (Li *et al.*, 2017) [22]. *Dimocarpus longan* cv. Shijia fruits treated with a unique chitosan/nano-silica hybrid film had a longer shelf life, less physiological weight loss, a lower browning index, and inhibited the development of malondialdehyde concentration and polyphenoloxidase activity in fresh fruit (Shi *et al.*, 2013) [37]. Apple fruits coated with polyvinyl chloride (PVC) film with nano-ZnO powder showed reduced rate of fruit decay, accumulation of malondialdehyde (MDA) and activity of polyphenol oxidase enzyme (Li *et al.*, 2011) [23].

Effect of nanofertilizers on nutrient content of fruit crops

Nano-fertilizers outperform even the most innovative modern conventional fertilizers in terms of effectiveness due to their high surface area to volume ratio. The plant nutrients encapsulated in Nano-particles also boost nutrient availability and consequently crop plant uptake. The greater mobility of Nano-particles results in the transfer of Nano-formulated nutrients to all parts of the plants. Leaf nanopores and stomatal openings promote nanomaterial uptake and penetration deep into the leaves. Increased nutrient transport and delivery through plasmodesmata, that are nanosized (50–60 nm) ion transfer channels between cells. Thus, application of nanofertilizers as soil or foliar application significantly increased the leaf nutrient content of the fruit crops.

Application of Nano NPK @ 1000:500:500 g/palm on the leaves of date palm significantly increased the leaf nitrogen content, leaf phosphorous content and leaf potassium content of date palm (Roshdy and Refaai, 2016) [29]. The higher leaf NPK content in *Punica granatum* cv. Malase Saveh was found with foliar application of Nano-Se @ 2 µM (Zahedi *et al.*, 2019) [43]. Soil application of 100 g of nano-powder potassium sulfate/vine resulted in higher leaf calcium content, leaf magnesium content and leaf zinc content in grapevine cv. Crimson Seedless (Shalan, 2020) [34]. Davarpanah *et al.* (2016) [13] found higher leaf zinc and leaf boron content in the leaves of pomegranate cv. Ardestani with foliar application of nano $ZnSO_4$ @ 120 ppm and nano boron @ 6.5 ppm. The application of Nano-zinc @ 1 g/L resulted in higher leaf NPK and leaf zinc content in mango cultivars (Zagzog *et al.*, 2017) [42]. Foliar application of Nano boron @ 270 ppm resulted in higher leaf boron content and leaf iron content in leaves of olive cv. Zard (Rohi Vishekaii *et al.*, 2021) [27]. Genaidy *et al.* (2020) [17] found higher leaf nitrogen content, leaf phosphorous content and leaf iron content with foliar application of nano-boron at 10 ppm + nano-zinc at 100 ppm in olive cv. Picual.

Nanofertilizers for mitigating abiotic stress in fruit crops

Abiotic stresses such as high temperature, low temperature, drought, flooding, salinity, alkalinity, nutrient deficiency or toxicity, etc. adversely affect the growth and development of fruit crops, resulting in a reduction in yield of fruit crops. Plants are subjected to a variety of environmental stresses during their life cycle, thus they evolve defense mechanisms at multiple levels by altering physiological, biochemical and molecular pathways. To deal with these challenges, plants take molecular approaches through suitable gene expression changes. Several studies have found that the influence of nanoparticles on plant growth and development is dependent on the concentration. Nanoparticles play a role in increasing the activity of antioxidant enzymes such as catalase (CAT), superoxide dismutase (SOD) and peroxidase (POD) (Laware and Raskar, 2014) [21].

Nanofertilizers along with sea weed extract significantly improved vine growth, fruit yield, fruit quality parameters and leaf nutrient content of grapes cv. Narince under alkaline soil condition (Sabir *et al.*, 2014) [31]. In salt-stressed plants, nano-silicon oxide treatment retained chlorophyll content, epicuticular wax structure, and carotenoid content while accumulating less proline in the leaves. As a result, nano-silicon oxide reduced the negative effects of salinity on the epicuticular wax layer of strawberry plants, increasing salt tolerance in strawberries (Avestan *et al.*, 2019) [6]. In comparison to Fe-EDTA, the application of low amounts of iron nanoparticles (0.8 ppm) can greatly ameliorate the deleterious effects of salt and drought in strawberry cv. Queen Elisa (Mozafari *et al.*, 2019) [24]. The use of zinc oxides increases tolerance to water stress, which protects plants from dehydration (Sedghi *et al.*, 2013) [33], whereas the use of zinc oxides with iron nanoparticles helps to reduce salinity stress (Solimon *et al.*, 2015) [39].

Conclusion

The use of nanofertilizers on fruit trees contributes effectively to improving the fruit quality and increasing the productivity of trees. Nanofertilizers are next-generation technology that can be used to improve existing farming systems. It reduces environmental pollution by reducing the amount of fertilizers used, which is positively reflected in the increased economic return of the farmers. When very low quantities of nanofertilizers are sprayed on fruit trees, these compounds have a significant influence by enhancing the growth, yield, quality, and leaf nutrient content of these fruit crops. Various nanomaterials have demonstrated possible applications in fruit crops in terms of plant vigour, yield enhancement and environmental stability. Nanofertilizers are a new potential tool to increase the abiotic stress tolerance in fruit crops. There is a need for further research to study the effects of different concentrations of nanoparticles on different fruit crops under variable climatic conditions.

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