www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(6): 831-836

www.thepharmajournal.com
Received: 12-04-2022
Accepted: 16-05-2022

Shilpa
Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Rupinder Singh
Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Chander Kant
Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Nishant Prashar
Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author
Rupinder Singh
Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Role of nanofertilizers in horticulture: A review

Shilpa, Rupinder Singh, Chander Kant and Nishant Prashar

Abstract
Fertilizers containing essential nutrients are added to the soil to improve fertility. As use of inorganic fertilizers increased, ecological and environmental concerns has also increased. To hamper such impacts, certain new technology has been introduced to maximize the yield without any leaching loss. Nanofertilizers are nutrient fertilizers containing Nano-structured formulations applied to plants that allow slow but efficient uptake of active components. Nanofertilizer has countless advantages; it can be used to control over accumulation of salt in soil and can be synthesized according to the nutrient requirement of plants. In horticulture crops like fruits, vegetables, flowers, spices, medicinal and aromatic plants nanofertilizers has successfully increased the yield, nutritive content and improved the physiological and biochemical characteristics as well as global food security. Through different research paper we have observed that nanofertilizers are beneficial to increase the productivity, quality as well as shelf life through their positive effects on physiological, morphological**,** physicochemical and molecular traits. In fruits and vegetables, nanofertilizers are used to increase the yield, chlorophyll content, protein percent and many other factors. Likewise benefits of nanofertilizers in other horticultural crops are also discussed in this paper.

Keywords: Nanotechnology, nanofertilizer, nano urea, nano NPK, nano Zn, nano iron, nano silver

Introduction

The World population is estimated to increase 9.7 billion by 2050 (FAO, 2018). Now days one of the serious challenge is to meet actual and future global food demands. Crop production will need to be raised by up to 70% to meet future food demands. Fertilizers have been used for the past many years for the benefit of farmers but it was monitored that intensive use of fertilizers affected the soil quality and harmful to human beings as well as environment.

The development of agriculture sector is possible by improving resource use efficiency and with appropriate usage of modern technologies. Nanotechnology has a lot of potential for making agriculture more sustainable, especially in developing countries.

Nanostructured formulations, which use processes such as targeted delivery, slow/controlled release and conditional release to release active ingredients in response to biological demands, have the potential to alter agricultural systems. The nano-sizing of these fertilizers increases the availability of nutrients to nano-scale plant pores, resulting in higher nutrient utilization efficiency. Nanoparticles help seeds germinate faster, boost agricultural yield, and improve chlorophyll content. This is easy for tiny pores on the plant's body surface to absorb and helps in plant growth. One of the most important applications of nanotechnology is nanofertilizer, which improves plant's ability to absorb nutrients and Nanofertilizers like Zn, Cu and Fe resolve soil fixation difficulties and maximize photosynthetic efficiency. According to studies, the use of nanofertilizers promoted the nutrient utilization efficiency, reduced soil toxicity, minimized the negative effects of overdosing and lowered the frequency of treatment (Ditta, 2012) [10]. Nanofertilizers are the nutrient carriers developed using substrates of 1-100 nm nano-dimensions used solely or in combination to improve plant growth, yield and performance of plant. These are made from conventional fertilizers extracted from different plants or plant parts by coating them with nanomaterials. Nanofertilizers have many other names like nano-carriers, nano-enabled fertilizers, bio-nanofertilizers, controlled released nanofertilizers, NPs-based nutrient and nano-based delivery systems of micronutrients, which delivers nutrients at the right time and in the right place (Gomes *et al.*, 2021) [16].

Nanofertilizers play a significant role in physiological and biochemical processes by improving nutrient availability, which can help in the enhancement of metabolic processes and stimulate meristematic activities, resulting in increased apical growth and photosynthetic area. It is crucial for increasing vegetative growth, improving reproductive growth and flowering and so increasing productivity, product quality, and shelf life of fruits.

Nanofertilizers balance the release of nitrogen, phosphorus and other macronutrient fertilizers absorbed by the plant. It also avoids nutrient losses and unwanted interactions of nutrients with water, air and especially microorganisms (Blois *et al.*, 2018) [7].

To maximize the effectiveness of nutrients for plant growth, nanofertilizers can adjust the pace at which nutrients are supplied based on environmental factors such as temperature fluctuations, soil moisture percentage and soil acidity. Nanofertilizers are preferred above traditional fertilizers due to their efficiency and capacity to be easily absorbed by shoots and roots due to controlled nutrient delivery (Khan and Rizvi, 2017) [23]. Nanofertilizers are used to reduce nitrogen loss from leaching, emissions, and long-term interactions with soil microorganisms.

Mainly Nanofertilizers are divided into three categories: micronutrient Nano- formulations, macronutrient nano-formulations and nutrients-loaded nanomaterials. Some of the potential nanofertilizer designs that have been used include pH release, heat release, ultrasonic release, magnetic release, specific release, slow release, rapid release and moisture release. Nanofertilizers can increase the nutrient delivery of fertilizers applied to the soil and reduce nutrient loss due to leaching (Manjunatha *et al*., 2016) [27].

Effect of Nanofertilizers on Fruit Crops

Fruits are the important source of nutraceuticals but depletion of nutrients in soil affects the cultivation and quality of fruits. Reason for the poor quality produce is the poor efficiency of conventional fertilizers i.e. about 20% of fertilizer is used by the crop and rest leached to the groundwater. Researchers reported the usage of nanofertilizers in fruit crops and divided them into functional categories such as direct soil application, irrigation, and foliar treatment.

In Date Palm, application of nutrient and nano NPK fertilizer enhanced vegetative growth and increases the yield. Nano NPK and conventional fertilization on date palm observed that quality, yield and growth rate of dates increased with low concentration of nano NPK fertilization (Roshdy and Refai, 2016) [36]. In Pomegranate, foliar spray of nano Zinc and nano Boron increased the fruit quality, yield, TSS, maturity indices, juice and decreased the total acidity (Davarpanah *et al.*, 2016) [9]. In mango, Nano Chitosan and Nano Potassium silicate of different concentrations were applied. Both nanofertilizers showed positive effect on flowering, fruit set, yield, and chlorophyll content of leaves. Nano K silicate has increased the panicle length, decreased the floral malformation and gave highest yield with best fruit characteristics (Mohamed Gad *et al.*, 2021) [40]. Similarly nano Boron shows positive effect in increasing yield and chemical properties of fruit and enhanced the content of chlorophyll and essential nutrients like Nitrogen, Potassium, Phosphorus, Manganese, Magnessium, Boron, Zinc and Iron in leaves (Abdelaziz *et al.*, 2019) [2]. In grape, research was carried out to study the effect of nano Carbon and Nitrogen fertilization levels on leaf mineral content, growth, fruit quality and yield of 3 year old seedless grapevines. The results showed that combining 80 percent nitrogen with 0.6 percent carbon nano tubes (CNTs) enhanced leaf area, fresh and dry weight, total carbohydrate % and concentration of N, P, K, Fe, and Mg in leaves, weight and juice content of 100 berries. It also showed that when nitrogen fertilizer was mixed with nano Carbon, fertilization rate of nitrogen fertilizer improved, potentially save the Nitrogen fertilizers amounts in production (Abdel-Hak *et al*, 2018) [3]. Nano Calcium based fertilizers improve foliage development, chlorophyll content provides best yield and improves quality of berry and nutrient content of leaf (Sabir *et al.*, 2014) [37] and Fruit quality was best on vines fed with 0.1 percent amino mineral nanofertilizer (Wassel *et al.*, 2017) [44]. Apple cultivar Golden Delicious, Red Delicious and Starking Delicious when treated with 1g/pot with given nano-biofertilizer had positive impact on plant i.e. it results in increased plant height, stem diameter, leaf area and chlorophyll content (Mohasedat *et al.*, 2018) [30]. Nano Calcium effect on quantitative and qualitative characteristics of apple was evaluated. 5 sprays at 2 week interval of growing season show positive effect on fruit quality and quantity. It increases the total phenolic content, total antioxidant activity fiber and starch content and decreases the TSS, Total sugars and anthocyanin content (Ranjbar *et al.*, 2020) [33]. Effect of nano packaging (PVC) film with Nano ZnO powder was examined on the preservation quality of Fuji apple slices at 4ºC for 12 days. Results showed that Nano Zinc active packaging extended the shelf life of freshly cut slices of apple and slowed down the fruit degradation and inhibited the accumulation of malondialdehyde (X. Li *et al.*, 2011) [25]. Effect of spraying pomegranate fruits with nitrogen fertilizer in nano-form (nN) and urea in Ardestani cultivar was investigated. Results obtained from the research indicated that Nano Nitrogen at 1.8 kg ha^{-1} gave highest yield and more number of fruits per tree (Davarpanah *et al*. 2017).

In citrus, 3 month old seedling were treated Nano NPK concentrations of 150, 300, 450 mm/l. Results shows that concentration of 450 mg.L^{-1} gives highest values for total leaf area, shoot and root dry weight and resulted in largest seedling stem diameter. It was concluded from the study that saplings treated with Nano NPK were ready for grafting as a rootstock in shorter period of time when compared with untreated saplings (Al-Jilihawi *et al.*, 2020) [6]. In peach, Spray of Silver nano-particles at 15 ml/l recorded maximum leaf area, chlorophyll content, shoot diameter, flower percentage, fruit yield and fruit physical and chemical properties. Ag Nanoparticles increased the pollen size and increases the pollen viability (Mosa *et al.*, 2021) [31].

Table 1: Effect of nano fertilizers on fruit crops

S. No.	Crop	Nano fertilizers used	Effect	Reference
1.	Apple	Nano ZnO	Extended the shelf life and Lowered the degradation	X. Li *et al.*, 2011 [25]
		Nano Biofertilizer	Increased plant height, plant diameter, leaf area and content of chlorophyll	Mohasedat *et al.*, 2018 [30]
		Nano Ca	Improved fruit quality and increased, total antioxidant activity, phenolic content, starch and fiber content	Ranjbar *et al.*, 2020 [33]
2.	Pomegranate	Nano Zn & Nano B	Increased fruit yield, quality, TSS and juice content. Decreased total acidity	Davarpanah *et al.*, 2016 [9]
3.	Mango	Nano Chitosan & Nano Potassium Silicate	Both fertilizers showed positive effect on flowering, chlorophyll content, fruit set and yield. Nano K silicate increased panicle length, high yield and best fruit	Mohamed Gad *et al.*, 2021 [40]

			characteristics. Decreased the floral malformation.	
		Nano B	Positive effect in increasing yield and chemical attributes of fruit. Enhanced the content of chlorophyll and essential nutrients like N, K, P, Mg, Mn, Zn, B and Fe in leaves.	Abdelaziz *et al.*, 2019 [2]
4.	Grape	Nano C	Increased weight of berries, leaf area, and total carbohydrate and increased the N, K, P, Fe and Mg content in leaves.	Abdel-Hak *et al.*, 2018 [3]
		Nano Ca	Increased foliage development, chlorophyll content and yield. Improved berry colouration	Sabir *et al.*, 2014 [37]
		Amino Nanofertilizer	Enhanced the fruit quality	Wassel *et al.*, 2017 [44]
5.	Citrus	Nano NPK	Highest total leaf area, seedling stem diameter, dry weight of root and shoot.	Al-Jilihawi *et al.*, 2020 [6]
6.	Date palm	Nano NPK	Increased the growth rate, yield and quality.	Roshdy and Refai, 2016 [36]
7.	Peach	Nano Ag	Increased leaf area, chlorophyll content shoot diameter, flower percentage and fruit yield and Improved physical and chemical properties of fruit.	Mosa *et al.*, 2021 [31]

Effect of nano fertilizers on Vegetable Crops

Agriculture is the backbone of developing countries, as the majority of people rely on it for a living. The world population is increasing day by day and it is required to increase productivity which can be increased by expanding cultivated area or by increasing crop yield through fertilizers. Presently, nanofertilizers plays important role as they are more efficient than conventional fertilizers. Nanotechnology in vegetable production has vast exploration including improved germination of seeds, seedling growth, abiotic and biotic stresses detection and management, yield and quality enhancement and till now proved to be an effective and promising tool in modern agriculture.

Tomato gave most number of fruit and increased weight and diameter of fruit observed with 300 kg/ha K nanofertilizers; stem diameter and plant height increased when 400 kg/ha K nanofertilizers is applied (Ajirloo *et al.*, 2015) [5]. Nanonat and Ferbanat applications at a rate of 3 l/ha have been observed to increase tomato yield, plant growth, and quality (Ekinci *et al.*, 2012). Water use efficiency (WUE), fertilizer use efficiency (FUE) and agronomic use efficiency (AUE) increased by fertigation with nano NPK fertilizers in potato cv. Arizona (Hayyawi *et al.*, 2019) [18]. In cucumber, Nanofertilizer NPK provided the best growth characteristics, yield and fruit quality. Increase in plant height, no. of leaves, chlorophyll and NPK % in leaves were recorded highest in all nanofertilizer treatments. After 21 days at 5^{o} C, application of NPK resulted in the least weight loss and decay percent and gave best overall appearance (Merghany *et al.*, 2019) [29] and also when Ferbanant nanotechnology liquid fertilizer @ 3 kg/ha is applied it gave highest fruit diameter and Nanonat @ 3 l/ha gave highest TSS (Meleck Ekinci *et al.*, 2014) [28]. In Faba beans, protein and chlorophyll content increases at higher concentration of nano iron and grain yield increased when 6 mg/l of nano iron applied (Nadi *et al.*, 2013) [32]. In cabbage, adding nano-thiophenols and nano-hydroquinone to nitrogen fertilizer improved the intake of nitrogen, phosphorus, potassium, and increases the chlorophyll content (Wang *et al.*, 2011). Higher nutrients on post-harvest soil are provided by foliar nano NPK application in Okra at 0.4 percent (Nibin *et al.*, 2019). Foliar application of ZnO nanoparticles improved drought stress tolerance in eggplant grown in salt-alkaline soil. Water-stressed eggplant treated with 50 or 100 ppm ZnO NP produced 25.6% and 33.1% more fruit. It was observed that using ZnO NP as a foliar spray for eggplant boosted water productivity. The use of ZnO NP (100 ppm) for alleviating water stress effects on eggplant production in dry-land agriculture was found to be beneficial (Semida *et al.*, 2021) [40]. In cabbage, higher head circumference and head height was recorded when plant treated with NPK and nano Fe (Abdulhameed *et al.*, 2021) [4]. Under waterlogging and saline conditions in Red cabbage and Broccoli, treatments with Nano Se, Nano Cu proves their effectiveness by improving plant growth and productivity and by enhancing the tolerance power of plants to insects (Ahmed El- Henawy *et al.*, 2018) [11]. Application of Silver nanoparticles (15 ppm) in rapeseed and cucumber, reduced pathogen infestation of seeds, increased chlorophyll content and stomatal conductance. It shows positive effects on the physiological processes, yields and productivity of plants (Jaskulski *et al.*, 2022) [21].

Table 2: Effect of nano fertilizers on vegetable crops

S. No.	Crop	Nano fertilizers used	Effect	Reference
1.	Potato	Nano NPK	Increased WUE, FUE and AUE.	Hayyawi *et al.*, 2019 [18]
2.	Tomato	Nano K	Increased the no. of fruits, weight, diameter of fruit, and increased the plant height and stem diameter.	Ajirloo *et al.*, 2015 [5]
3.	Cucumber	Nano NPK	Best growth characteristics, yield and fruit quality. Highest leaves, chlorophyll content. Lowest weight loss and decay % in storage conditions.	Merghany *et al.*, 2019 [29]
4.	Faba beans	Nano Fe	Increased the concentration of protein and chlorophyll content.	Nadi *et al.*, 2013 [32]
5.	Cabbage	Nano Hydroquinone & Nano-thiophenols	Improved the absorption of NPK and increased the production of chlorophyll.	Wang *et al.*, 2011
		Nano Fe & Nano NPK	Increase head circumference and head height.	Abdulhameed *et al.*, 2021 [4]
6.	Okra	Nano NPK	Provided the high nutrients to the soil.	Nibin *et al.*, 2019
7.	Brinjal	Nano ZnO	Increased the no. of fruits and ameliorated the water stress effect on production.	Semida *et al.*, 2021 [40]
8.	Rapeseed and Cucumber	Nano Ag	Reduced pathogen infestation of seeds, increased the chlorophyll content and stomatal conductance.	Jaskulski *et al.*, 2022 [21]

Effect of nano fertilizers on spices, medicinal and aromatic plants

In sweet basil, use of Fe_2O_3 nanoparticles resulted in increased plant growth, iron content as well as oil content (Elfecky *et al*., 2013). Application of nanofertilizers P, K and Fe to Saffron (*Crocus sativus*) ecotypes had positive effect on flowering and yield (Amirnia, 2014). In Peppermint (*Mentha piperta* L.), the treatment with Fe, Zn, and K nanofertilizer resulted in the greatest number of branches, leaves of branches, highest height, wet and dry weight of leaves, wet and dry weight of stems and wet and dry weight of plant (Hassani *et al.*, 2015) [17]. Nano fertilizers also increased the yield and yield components of black cumin (*Nigella sativa*) and also showed significant effect on seed weight, seed yield, biological yield and harvest index (Safaei *et al.*, 2014) [38]. Photosynthetic pigments and aerial dry weight of black cumin were significantly affected by the interaction impact of foliar application of nano iron oxide particles and biofertilizers (Sivieri *et al.*, (2021) [8]. Application of Nano Zn fertilizer at drought stress level in fennel crop increased the grain yield. It also improved the concentration of anethole and esrogel but the concentration of fenecon and limonene decreased (Heydarnejadiyan *et al.*, 2021). Nano Zn, Nano Fe and Nano Mn in black cumin showed positive effect on yield components, seed yield, essential oil percentage and yield of essential oil. It improved the qualitative and quantitative yield of black cumin (Rezaei-Chiyaneh *et al.*, 2018) [35]. In fennel, TiO_2 spray significantly raised photosynthetic activity and improved the growth of fennel plant. With 6 ppm concentration, highest no. of branches, tallest plants and highest fruit yield was observed. TiO_2 concentrations in fennel also show highest values of pigments, carbohydrates, sugars and NPK content (Khater, 2016) [24]. Nano silicon in coriander enhanced morphological traits and increased the content of chlorophyll a, b and total chlorophyll content, carotenoid and carbohydrate content in leaves. It reduced the negative effect of lead stress in coriander by increasing lead concentration in soil (Fatemi *et al.*, 2017) [14].

Table 3: Effect of nano fertilizers on spices, medicinal and aromatic crops.

S. No.	Crop	Nano fertilizers used	Effect	Reference
1.	Sweet basil	Nano Fe_2O_3	Improved the plant growth and oil content.	Elfecky *et al*., 2013
2.	Saffron	Nano P, K and Fe	Positive effect on flowering and yield.	Amirnia, 2014
3.	Peppermint	Nano Fe, Zn and K	Highest no. of branches leaves height and wet and dry weight of leaves, stem and plant.	Hassani, A. *et al.*, 2015 [17]
4.	Black cumin	Nanofertilizer (Pharmks®)	Increased seed weight, seed yield and biological yield Significant effect on photosynthetic activity.	Safaei *et al.*, 2014 [38]
		Nano FeO	Increased aerial dry weight and pigments.	Sivieri *et al.*, 2021 [8]
		Nano Zn, Nano Fe and Nano Mn	Increased seed yield, essential oil percentage and essential oil.	Rezaei-Chiyaneh *et al.*, 2018 [35]
5.	Fennel	Nano Zn	Improved the concentration of anethole and esrogel.	Heydarnejadiyan *et al.*, 2021
		Nano TiO_2	Highest no. of branches Increased the plant height and yield	Khater, 2016 [24]
6.	Coriander	Nano Si	Improved the morphological traits and increased the chlorophyll, carotenoid and carbohydrate content.	Fatemi *et al.*, 2017 [14]

Effect of nano fertilizers on Flowers

In flowers, nanofertilizers play significant role to enhance the flower quality. When 1.8 mg/L Iron Chelate nanofertilizers applied in combination with or without cycocel 1000 mmg/L to *Euphorbia pulcherrima*, it showed short height, more leaves, more shoots and root length and more volume with permanent coloured bracts. Leaf surface was more in plants with 1.8 gl^{-1} Iron nanofertilizer without cycocel and reduced root volume and maximum chlorophyll content was seen with Fe nanofertilizer with cycocel concentrations (Kaviani *et al.*, 2016) [22]. Effect of K and Nano K on biochemical and physiological traits of Asiatic Lilium Hybrid cv. Tresor. Nano K when applied as a foliar spray and recorded results shows that highest stem fresh weight was observed in 0.5 mM nano-K and overall 2 mM nano K showed the best results and recommended for use (Abbasi *et al.*, 2019) [1]. In Gladiolus, application of Nano NPK at 1 g/l gave highest spike stem diameter, flower diameter and increases the dry weights of spikes. It was noticed that nano NPK at 1 g/l in combination with Moringa leaf extract at 10% provides best results in flowering and chemical constituents of flower (Sarhan *et al.*, 2022) [39]. Application of K nano-chelatein marigold increased the shoot fresh weight, dry weight of shoot and root of flower, peroxidase activity and proline and glycine betaine content under drought stress conditions (Erfani Alamdari *et al.*, 2021) [12]. Nano NPK in Rosemary plant shows superior results in height, no. of branches, oil quantity and density and in active compounds present in plant (Mahwish *et al.*, 2021) [26].

Table 4: Effect of nano fertilizers on flowers

S. No.	Crop	Nano fertilizers used	Effect	Reference
1.	Poinsettia	Nano iron chelate	Short height, more no. of leaves, increased the volume and length of shoot, permanent coloured bract.	Kaviani *et al.*, 2016 [22]
2.	Asiatic lilium var.Tresor	Nano K	High stem fresh weight.	Abbasi *et al.*, 2019 [1]
3.	Gladiolus	Nano NPK	Increased the diameter of flower and spike stem and dry weight of spikes.	Sarhan *et al.*, 2022 [39]
4.	Marigold	Nano chelatin	Increased the fresh weight of shoot, peroxidase activity, proline and glycine content.	Erfani Alamdari *et al.*, 2021 [12]
5.	Rosemary	Nano NPK	Improved the height, number of branches, oil quantity, density and active compounds in flower.	Mahwish *et al.*, 2021 [26]

Constraints of Nanofertilizers in Horticulture

In horticulture, nano fertilizers are excellent for horticulture farming systems and sustainable agricultural strategies. It offers numerous benefits in the cultivation of high-quality, high-yielding crops. Plants potential uptake of nanoparticles, as well as their biotransformation and translocation pathways, has a variety of beneficial and negative consequences. The development and deployment of nanoparticles as nanofertilizers is hampered by a lack of recognized formulations, thorough monitoring, and risk management (Iqbal, 2019) [20]. Nanomaterials have been identified to be associated with soil microbes and change nutrient uptake in plants, owing to their potential to alter inter - cellular activity (Singh, 2017) [41]. In humans, nanoparticles have negative impact as they can easily enter into the biological systems and are able to cross cell membrane. While spraying these nanoparticles, there is possibility that they can reach the target sites like liver, brain or heart and (Steve Suppan, 2017) [43]. There are findings that conclude that nanofertilizers have negative impacts and systematic assessment of the adverse impacts on all associated risks, including human health risk, food security, the ecosystem of nanofertilizers, standardized formulas for crops, and guidelines, must be carried out. From this we can conclude that nanofertilizers with standardized stable formulation must be developed with an aim to provide proper safety and prevent lethal effects.

References

1. Abbasi F, Khaleghi A, Khadivi A. The Effect of Potassium and Nano-Potassium on Some Physiological and Biochemical Traits of Asiatic Lilium Hybrid cv. Tresor. Journal of Plant Productions (Agronomy, Breeding and Horticulture). 2019;42(2):253-264.
2. Abdelaziz FH, Akl AMMA, Mohamed AY, Zakier MA. Response of keitte mango trees to spray boron prepared by nanotechnology technique. NY Sci. J. 2019;12:48-55.
3. Abdel-Hak RS, El-Shazly SA, El-Gazzar AA, Shaaban EA. Effects of nano carbon and nitrogen fertilization on growth, leaf mineral content, yield and fruit quality of flame seedless grape. Arab Universities Journal of Agricultural Sciences, 26 (Special issue (2D)), 2018, 1439-1448pp.
4. Abdulhameed MF, Taha AA, Ismail RA. Improvement of cabbage growth and yield by nanofertilizers and nanoparticles. Environmental Nanotechnology, Monitoring & Management. 2021;15:100437.
5. Ajirloo AR, M Shaaban, Motlagh ZR. Effect of K nano-fertilizer and N bio-fertilizer on yield and yield components of tomato (*Lycopersicon esculentum* L.). Int. J. Adv. Biol. Biom. Res. 2015;3(1):138-143.
6. Al-jilihawi DAH, Merza TK. Effect of soil fertilization and foliar nano-npk on growth of key lemon *Citrus aurantifolia* rootstock saplings. Plant archives. 2020;20(2):3955-3958.
7. Blois L, Lay-Ekuakille A. Reliability and metrology features for manufacturing process of nanoelements for geo-environmental protection. In 2018 Nanotechnology for Instrumentation and Measurement (Nanofim) IEEE, 2018, 1-4p.
8. Bromand Sivieri M, Heidary M, Gholami A, Ghorbani H. Effects of foliar application of nano iron oxide and biofertilizers on the activity of antioxidant enzymes and some physiological characteristics of the root and aerial parts in black cumin (*Nigella sativa* L.). Iranian Journal of Horticultural Science. 2021;51(4):939-953.
9. Davarpanah S, Tehranifar A, Davarynejad G, Abadía J, Khorasani R. Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. Scientia horticulturae. 2016;210:57-64.
10. Ditta A. How helpful is nanotechnology in agriculture? Advances in Natural Sciences: Nanoscience and Nanotechnology. 2012;3:10.
11. El-Henawy A, El-Sheikh I, Hassan A, Madein A, El-Sheikh A, El-Yamany A, *et al*. Response of cultivated broccoli and red cabbage crops to mineral, organic and nano-fertilizers. Environment, Biodiversity and Soil Security. 2018;2:221-231.
12. Erfani Alamdari S, Rezaei MA, Farahvash F, Mahmood Janlou M. Effects of nano-potassium and potassium sulfate fertilizers and salicylic acid on the morpho-physiological traits of marigold, *Calendula officinalis* L., under drought stress. International Journal of Modern Agriculture. 2021;10(1):286-297.
13. Farina A, Ghorbani A. Effect of K Nano-fertilizer and N-Bio fertilizer on yield and yield components of red bean (*Phaseolus vulgaris* L.). Intl. J of Biosci. 2014;5(12):296-303.
14. Fatemi H, Esmaielpour B, Soltani-Toolarood AA, Nematolah Zadeh A. Effects of silicon nano-particle nutrition on growth and physiological characteristics of *Coriandrum sativum* L. under lead stress. Iranian Journal of Medicinal and Aromatic Plants Research. 2017;33(5):853-870.
15. Gad M, Abdel-Mohsen M, Zagzog O. Improving the yield and fruiting characteristics of Ewais Mango Cultivar by spraying with Nano-chitosan and Nano-potassium silicate. Scientific Journal of Agricultural Sciences. 2021;3(2):68-77.
16. Gomes DG, Pieretti JC, Rolim WR, Seabra AB, Oliveira HC. Advances in nano-based delivery systems of micronutrients for a greener agriculture. In Advances in Nano-Fertilizers and Nano-Pesticides in Agriculture, Woodhead Publishing, 2021, 111-143.
17. Hassani A, Tajali AA, Mazinani SMH, Hassani M. Studying the conventional chemical fertilizers and nano-fertilizer of iron, zinc and potassium on quantitative yield of the medicinal plant of peppermint (*Mentha piperita* L.) in Khuzestan. International Journal of Agriculture Innovations and Research. 2015;3(4):1078-1082.
18. Hayyawi WA, Al-uthery, Al-Shami MN, Qusay. Impact of fertigation of nano NPK fertilizers, nutrient use efficiency and distribution in soil of potato (*Solanum tuberosum* L.). Plant Arch. 2019;19(1):1087-1096.
19. Heydarnejadiyan H, Maleki A, Babaei F. The Effect of Zinc and Salicylic Acid application on grain yield, essential oil and phytochemical properties of fennel plants under drought stress. Journal of Essential Oil Bearing Plants. 2020;23(6):1371-1385.
20. Iqbal MA. Nano-fertilizers for sustainable crop production under changing climate: A global perspective. Sustainable crop production. 2019;8:1-13.
21. Jaskulski D, Jaskulska I, Majewska J, Radziemska M, Bilgin A, Brtnicky M. Silver Nanoparticles (AgNPs) in Urea Solution in Laboratory Tests and Field Experiments with Crops and Vegetables. Materials. 2022;15(3):870.
22. Kaviani, Behzad., Ghaziani MVF, Negahdar N. The effect of iron nano-chelate fertilizer and cycocel (ccc) on

some quantity and quality characters of *Euphorbia pulcherrima* Wild. J Medical and Bioengineering. 2016;5:41-44

23. Khan MR, Rizvi TF. Application of nanofertilizer and nanopesticides for improvements in crop production and protection. In Nanoscience and plant–soil systems, Springer, Cham, 2017, 405-427.
24. Khater M. Effect of TiO_2 nanoparticles spraying on fennel plant. Journal of Plant Production. 2016;7(1):29-34.
25. Li X, Li W, Jiang Y, Ding Y, Yun J, Tang Y, *et al*. Effect of nano-ZnO-coated active packaging on quality of fresh-cut 'Fuji'apple. International Journal of Food Science & Technology. 2011;46(9):1947-1955.
26. Mahewish HH, Radi FH, Radhi MN. Response of rosemary plant to the effect of Nano-NPK fertilizer and biological factors and their effect on the active substances. University of Thi-Qar Journal of agricultural research. 2021;10(1)39-48.
27. Manjunatha SB, Biradar DP, Aladakatti YR. Nanotechnology and its applications in agriculture: A review. J farm Sci. 2016;29(1):1-13.
28. Melek E, Dursun A, Yildirim E, Parlakova F. Effects of Nanotechnology liquid fertilizers on the plant growth and yield of Cucumber (*Cucumis sativus* L.). Acta Sci. Pol., Hortorum Cultus. 2014;13(3):135-141.
29. Merghany MM, Shahein MM, Sliem MA, Abdelgawad KF, Radwan AF. Effect of nano-fertilizers on cucumber plant growth, fruit yield and it's quality. Plant Archives. 2019;19(2):165-172.
30. Mohasedat Z, Dehestani-Ardakani M, Kamali K, Eslami F. The effects of nano-bio fertilizer on vegetative growth and nutrient uptake in seedlings of three apple cultivars. Adv. In Biores, 2018, 9(2).
31. Mosa WF, El-Shehawi AM, Mackled MI, Salem MZ, Ghareeb RY, Hafez EE, Abdelsalam NR. Productivity performance of peach trees, insecticidal and antibacterial bioactivities of leaf extracts as affected by nanofertilizers foliar application. Scientific Reports. 2021;11(1):1-19.
32. Nadi E, Aynehband A, M Mojaddam. Effect of nano-iron Chelate fertilizer on grain yield, protein percent and chlorophyll content of Faba bean (*Vicia faba* L.). Int. J Biosci. 2013;3:267-272.
33. Ranjbar S, Ramezanian A, Rahemi M. Nano-calcium and its potential to improve 'Red Delicious' apple fruit characteristics. Horticulture, Environment, and Biotechnology. 2020;61(1):23-30.
34. Remedios C, Rosario F, Bastos V. Environmental Nanoparticles interactions with plants: Morphological, physiological and genotoxic aspects. J Bot. 2012;8:1-8.
35. Rezaei-Chiyaneh E, Rahimi S, Rahimi A, Hadi H, Mahdavikia H. Response of seed yield and essential oil of black cumin (*Nigella sativa* L.) affected as foliar spraying of nano-fertilizers. Journal of Medicinal plants and By-product. 2018;7(1):33-40.
36. Roshdy KHA, Refaai MM. Effect of nanotechnology Fertilization on growth and fruiting of zaghloul date palms. J Plant Production. Mansoura Univ. 2016;7(1):93-98.
37. Sabir A, Yazar K, Sabir F, Kara Z, Yazici MA, Goksu N. Vine growth, yield, berry quality attributes and leaf nutrient content of grapevines as influenced by seaweed extract (*Ascophyllum nodosum*) and nanosize fertilizer pulverizations. Scientia Horticulturae. 2014;175:1-8.
38. Safaei Z, Azizi M, Davarynejad G, Aroiee H. The Effect of Foliar Application of Humic Acid and Nanofertilizer (Pharmks®) on Yield and Yield Components of Black Cumin (*Nigella sativa* L.). Journal of Medicinal plants and By-product. 2014;3(2):133-140.
39. Sarhan AM, Habib AM, Fahmy A, Noor El-Deen TM, Selim A. Effect of nano, bio, chemical fertilization and leaves extract of moringa plant on flowering and chemical constituents of gladiolus plant. Egyptian Journal of Chemistry. 2022;65(7):5-6.
40. Semida WM, Abdelkhalik A, Mohamed G, El-Mageed A, Taia A, El-Mageed A, *et al*. Foliar application of zinc oxide nanoparticles promotes drought stress tolerance in eggplant (*Solanum melongena* L.). Plants. 2021;10(2):421.
41. Singh NA. Nanotechnology innovations, industrial applications and patents. Environ. Chem. Lett. 2017;15(2):185-191.
42. Solanki P, Bhargava A, Chhipa H, Jain N, Panwar J. Nano-fertilizers and their smart delivery system, 2015, 81-101pp.
43. Suppan S. Applying nanotechnology to fertilizer: rationales, research, risks and regulatory challenges. The Institute for Agriculture and Trade Policy works locally and globally, Brazil. 2017.
44. Wassel AEH, El-Wasfy M, Mohamed M. Response of Flame seedless grapevines to foliar application of nano fertilizers. Journal of Productivity and Development. 2017;22(3):469-485.