



Review

Recent Trends in the Foliar Spraying of Zinc Nutrient and Zinc Oxide Nanoparticles in Tomato Production

Razu Ahmed ^{1,2}, Mohd Yusoff Abd Samad ¹, Md. Kamal Uddin ^{1,*} , Md. Abdul Quddus ² and M. A. Motalib Hossain ³ 

¹ Department of Land Management, Faculty of Agriculture, University Putra Malaysia, Serdang 43400, Malaysia; razuahmed52@yahoo.com (R.A.); myusoffas@upm.edu.my (M.Y.A.S.)

² Soil and Water Management Section, Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh; quddus06@yahoo.com

³ Nanotechnology and Catalysis Research Centre, Institute for Advanced Studies, University of Malaya, Kuala Lumpur 50603, Malaysia; motalib_123@yahoo.com

* Correspondence: mkuddin07@gmail.com

Abstract: Growing vegetables can be seen as a means of improving people's livelihoods and nutritional status. Tomatoes are one of the world's most commonly planted vegetable crops. The nutritional arrangement of the tomato depends on the quantity and type of nutrients taken from the growing medium, such as soil and foliar application; therefore, an adequate amount of macro- and micro-nutrients, including zinc (Zn) and zinc oxide nanoparticles (ZnO-NPs), are crucial for tomato production. Zinc foliar spraying is one of the effective procedures that may improve crop quality and yield. Zinc oxide nanoparticles (ZnO-NPs) are represented as a biosafety concern for biological materials. Foliar application of Zn showed better results in increasing soluble solids (TSS), firmness, titratable acidity, chlorophyll-a, chlorophyll-b, ascorbic acid, amount of lycopene. Researchers have observed the effect of nanoparticles of zinc oxide on various crops, including tomatoes. Foliar spraying of ZnO-NPs gave the most influential results in terms of best planting parameters, namely plant height, early flowering, fruit yields as well as lycopene content. Therefore, more attention should be given to improving quantity and quality as well as nutrient use efficiency of Zn and ZnO-NPs in tomato production. Recent information on the effect of zinc nutrient foliar spraying and ZnO-NPs as a nano fertilizer on tomato productivity is reviewed in this article.

Keywords: foliar spray; zinc nutrient; zinc oxide nanoparticle; tomato production; nutrient content



Citation: Ahmed, R.; Yusoff Abd Samad, M.; Uddin, M.K.; Quddus, M.A.; Hossain, M.A.M. Recent Trends in the Foliar Spraying of Zinc Nutrient and Zinc Oxide Nanoparticles in Tomato Production. *Agronomy* **2021**, *11*, 2074. <https://doi.org/10.3390/agronomy11102074>

Academic Editors: Sandra López-Rayó and Juan J. Lucena

Received: 11 August 2021

Accepted: 13 September 2021

Published: 16 October 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Vegetable production can be espoused as an effective tool for maintaining the lifestyle and nutritional status of the people. Tomatoes are one of the most widely grown, valuable, and consumed vegetables in the world, ranking second only to potatoes in terms of consumption [1]. It is measured as a perennial crop, but in the case of commercial productions, it is considered as a self-crossing annual crop [2]. Tomato (*Solanum lycopersicum*) is a popular vegetable crop and a good source of protein, calcium, iron (Fe), sodium (Na), potassium (K), magnesium (Mg), vitamin A, vitamin C, antioxidant and carotenoids, which help to prevent cancer and degenerative diseases [3]. Studies show that Zn plays a vital role in achieving higher yields and better quality of tomato. Several studies have noted that Zn is a vital nutrient element, which is required by all living organisms, and it ranks 23rd on the planet and is the second most abundant transition metal, following iron [4,5]. Zinc is an essential trace element in various plant functions, such as increasing the rate of enzymes, chlorophyll, antioxidants, and is a necessary constituent of numerous proteins [6]. Foliar application can expand the yield contributing character, fruit set, and fruit yield of tomato through photosynthesis of green plants [7].

Nanotechnology is a rapidly evolving technology that has the potential to usher in a new era of scientific discovery in every field [8]. Nanoparticles (NPs) are unit resources with a distinctive dimension from 1 to 100 nm and incredible structural and physicochemical characteristics due to their chemical, physical, biomedical, and optical properties [9]. Nanoparticles associate with plants, causing a variety of morphological and physiological changes depending on their properties. The efficiency of NPs is measured by their physical, chemical composition, size, shape, surface, and effective doses [10]. It was reported that the application of appropriate quantities of ZnO-NPs to the roots, shoots, and grains of wheat has an ability to control the plant's growth, recognizing that these nanoparticles are the source of Zn that can eventually alleviate Zn deficiency in plants [11]. Conversely, the excess concentration of ZnO-NPs meaningfully impedes tomato-root and -shoot growth, decreases the content of chlorophylls-a and -b, and ultimately hampers photosynthetic efficacy and some other chlorophyll fluorescence parameters [12].

However, the foliar application of boron (B) and Zn at the concentrations of 250 ppm and 150 ppm, respectively, showed better performance on the dry weight of leaves, stem, and root. For example, tomato yield represented the highest result by the foliar application of Zn at concentrations of 250 ppm [13]. The effective response was observed in the case of the number of branches per plant, stem diameter, and spread of plant at 1.0% foliar spraying of Zn with Fe and B in the chili plant [14]. Nawaz and co-workers [15] observed in their experiment that the maximum number of tomato fruits per plant was produced and the total yield of tomato (28.43 t ha^{-1}) was increased by 100% over control with the foliar application of 10 ppm Zn associated with the rate of 150 kg ha^{-1} , 100 kg ha^{-1} nitrogen (N) and phosphorus (P), respectively. The combined application of macronutrients in the soil, as well as a foliar spraying of the plant, was suggested to improve tomato qualities and yield [16]. The foliar spraying at 0.2% of zinc sulfate, ferrous sulfate, calcium nitrate with 0.1% spraying of B gave the most significant positive response in the case of growth, flowering, and yield and quality of tomato [17]. The root and shoot biomass were increased by 40.9% and 76.0%, respectively, over control in mungbean seedlings with an application of ZnO-NPs (20 ppm). Conversely, in chickpea seedlings, the root biomass and shoot biomass exhibited 37.1% and 26.6% growth, respectively, with an application of 1 ppm of ZnO-NPs [18]. This review has focused on recent developments in the application and impact of Zn nutrient and nanoparticles on tomatoes, as well as potential prospects and challenges.

2. Importance of Tomato

Tomato is one of the widespread fruiting-vegetable crops, which is grown throughout the world, and it stands in the second position behind potato in considering area, but in the case of a processing crop, it bears first-place worldwide [19]. It is categorized as an annual crop, planted in the warm period of a year with an average optimal rising temperature between 25°C to 29°C . Moreover, tomato relishes a significant position considering their nutritional value. Approximately 100 g of tomato fruits contain calcium 48 mg, ascorbic acid 27 mg, phosphorus 20 mg, carbohydrates 3.6 g, proteins 0.9 g, fiber 0.8 g, iron 0.4 g, fats 0.2 g, and energy 20 K cal. Tomato also encompasses lycopene pigments and β -carotene, where lycopene is the indicator of its red color. Tomatoes also preserve the blood vessels in good condition and protect them from scurvy diseases [20]. Tomato shows a major role in the human diet due to its rich source of lycopene, vitamins viz. ascorbic acid, and β -carotene, which are antioxidants and minerals, such as calcium [21]. In terms of human health, it is a prime component in the everyday diet due to it constituting a vital source of minerals, vitamins, and antioxidants [22]. Emphasis has recently been given to tomato in terms of their role in the recovery from different types of diseases. This attention is owing to the existence of carotenoids and particularly lycopene, which is an unsaturated allylic compound that performs by diminishing cellular aging and inhibiting cardiovascular risk, cancer, and others [23,24]. Tomatoes can be used in varied ways in the kitchen, e.g., ketchup, juice, pulp, etc. [25]. Tomato is an important crop in many markets around the world.

Nevertheless, the cost price and the quality are still considered as a great challenge due to varied global temperature and soil conditions [26].

3. Importance of Foliar Fertilization

Foliar application (Figure 1) is a method of plants nutrition that involves directly applying liquid fertilizer to the leaves rather than the soil. Foliar fertilization represents the application of nutrients by spraying to the plants' leaves and stems for absorption. The foliar fertilizers enhance the plant's yield, reduce diseases and pest infestation, influence drought tolerance as well as improve crop quality. The plant can only absorb a certain quantity of nutrients supplied by foliar spraying, so the foliar application should be applied as a supplementary form of nutrients but not replacing the basal dose of fertilizers. Conditions for the application of foliar fertilizers are as follows:

1. Foliar spraying should be in the early morning and late afternoon because the humidity is higher, and the leaves of plants are in a full turgor condition with their cells full of water.
2. Foliar spraying should be avoided during the warm hours of the day; plants can only absorb nutrients in a limited amount at high temperatures.
3. Foliar spraying should be applied under minimum wind conditions.
4. It should be sprayed at a time of sufficient soil moisture condition when leaves will be turgid and become less water-stressed, so irrigation is better before spraying.
5. Spraying should be avoided before rainfall.
6. The optimum pH of foliar spray is slightly acidic (5 ± 0.5).
7. A suitable wetting agent or surfactant for minimizing the surface tension of the spray droplets should be used, which ultimately maintain the proper distribution of the droplet, increase the wetted surface area, decrease the burning of the leaves as well as improve nutrient uptake by plants.
8. It should be ensured that the fertilizer is in a fully soluble condition [27].

The situation of nutrient uptake in the soil is not always entirely effective because of leaching, soil fixations, blockages, and other losses. These problems can be minimized by arranging foliar application. There are several advantages of foliar fertilizers because of three following main reasons: 1. Foliar fertilization is more efficient because the chelated nutrients are fully plant available. 2. It promotes the growth of the plants even in less favorable weather conditions. 3. It is an environmentally friendly solution [28]. On the other hand, bio stimulants act as an additive to the fertilizer and give support for the uptake of nutrients, enhance plant growth, and improve tolerance to abiotic stress. These cannot serve as fertilizers because of their inability to supply nutrients directly to the plants. These may assist the gain of nutrients by enhancing metabolic processes in the soil and plants [29]. Foliar fertilization can supply nutrients directly to the plant, so this method is better than bio stimulant applications.

The most effective foliar applications are when a plant lacks nutrients. Narimani and colleagues observed that the foliage application of microelements could increase the competence of micronutrient activities [30]. Bozoglu et al. [31] identified that foliar spraying of Zn could enhance higher yield attributes, yield, and quality of chickpea.

Foliar application of micronutrients is one of the most effective tools in terms of the quick response of microelements when roots fail to provide adequate supply [32]. Foliar spraying of microelements is a more appropriate approach than those of the soil application because of its various activities, such as overcoming nutrient deficiency quickly, relaxed application, decreasing the toxicity created by the accumulation in the roots, and stopping nutrient fixation by the soil [16]. Micronutrients have an impressive action in the development of different plant parts as well as and foliar spraying of these micronutrients can increase the vegetative and reproductive growth, setting of fruit, quality, and yield attributes of tomato by ensuring the photosynthesis effects of green plants [7]. So, the foliar spraying is the real method to nourish the tomato crop by enriching the growth, quality, yield contributing characters, and remarkable yield [17]. It is noted that balanced fertilization of major and minor nutrients can improve the production of crops, where foliar

spraying of micronutrients is not only an effective approach but also a secured system of fertilizer application [33,34]. Therefore, foliar spraying is a more applicable method than soil application for quick nutrient uptake [35].

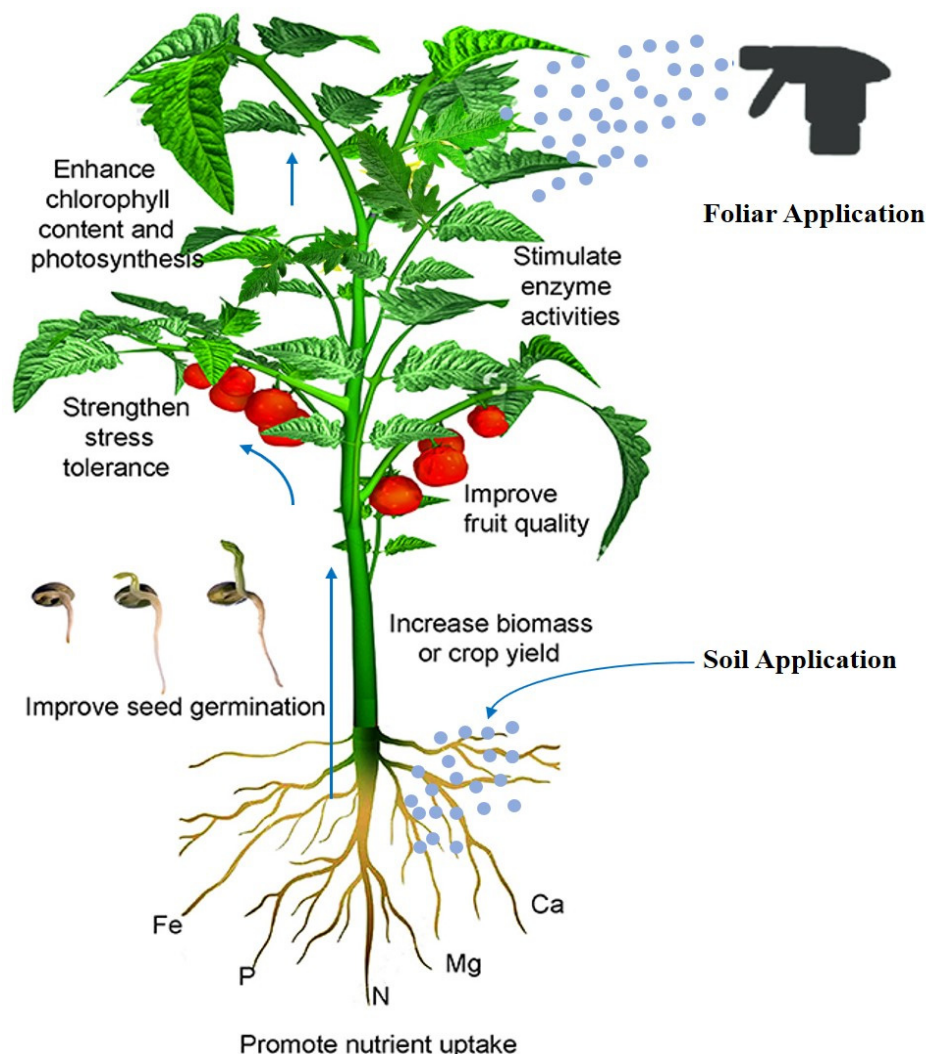


Figure 1. Method of foliar fertilization.

4. Importance of Zinc Nutrient on Tomato Plants

Zinc is an essential micronutrient that enhances enzyme reactions similar to manganese and magnesium, and it can improve the effectiveness of photosynthesis and enhance the antioxidant system of tomato plants [36]. In addition, in conjunction with boron, Zn aids in the synthesis of auxin, growth of cell walls, and cellular proliferation in plants [37]. Zn plays a key role in managing the generation and detoxification of free oxygen radicals, which can damage membrane lipids and sulfhydryl groups, and it is also necessary for the production of the carbonic anhydrase enzyme which supports the transport of CO₂ throughout photosynthesis [38].

Furthermore, Harris and co-workers found that Zn is responsible for RNA metabolism, encouraging the formation of carbohydrates, proteins, and DNA, increased seed generation, fruit set, the number of fruits per plant, fruits' length and diameter, fruits' dry weight, the sum of seeds per fruit, and seed yield per plant [13]. The maximum number of fruits per cluster, fruit set, fruit weight, number of fruits per plant, fruit yield per plant, higher total soluble solids (TSS), and vitamin C were increased by the application of zinc nutrients in the tomato plant [39]. Abedy [40] reported that this micronutrient has also displayed a

key role in precipitating photosynthesis and related enzymes, which are responsible for increasing sugar and decreasing acidity. The deficiency of Zn also affects the growth of various crops. The maximum TSS, chlorophyll-a, chlorophyll-b, vitamin C, flavonoids, carotenoids, and phenolics were recorded in plants treated with the application of zinc nutrients at 30 ppm in the tomato plant [41]. Passam and other fellow plant workers [42] also identified various malformations, such as shorter and thinner internodes, stunted growth, chlorotic spots on older flooring, and the upward twisting of the leaf borders in Zn-deficient plants. The maximum plant height (cm), number of branches per plant, number of leaves per plant, first day flowering at 29.68 days, number of fruits per plant (28.33), fruit weight per plant (1.38 kg), and fruit yield flowering at 29.68 days, number of fruits per plant (28.33), fruit weight per plant (1.38 kg), and fruit yield (51.12 t ha^{-1}) were obtained under 10 Zn kg ha^{-1} [43]. Sultana et al. [16] also found that the tomato yield, both quantity and quality, meaningfully responded to foliar spraying of B and Zn nutrient. They also observed that foliar fertilization, consisting of Zn and B at 0.05% and 0.03%, respectively, accomplished the maximum fruit yield (85.5 t ha^{-1} and 81.7 t ha^{-1} in 2013 and 2014, respectively), while the control cropping plot achieved 66.8 and 60.7 t ha^{-1} in 2013 and 2014, respectively.

5. Effect of Zinc Sulfate Fertilizer on Tomato

Until now, various experiments have been carried out to observe the effect of ZnSO_4 fertilizer on the tomato plant. In an experiment by Harris and co-workers [13], at 80 and 95 days after transplant, the highest plant height was observed in the combined application of H_3BO_3 (350 ppm) along with ZnSO_4 (350 ppm). Recently, Haleema and colleagues [44] showed that, with a foliar application of 0.5% Zn, maximum tomato plant height (86.53 cm), number of primary branches (2.53) and secondary branches (6.42), leaves per plant (167), leaf area (63.33 cm^2), and fruits per plant (63.78) were attained.

The fruit yield of two tomato variants, VCT-1 and Rio Grande, was improved by 39% and 54% over the control variant with the application of Zn at 10 mg/kg soil, whereas the yield of tomatoes was improved by 34 and 48%, respectively, at 15 mg kg^{-1} of soil application. Therefore, it has been suggested that soil application at 10 ppm has a positive impact on the yield and quality of fruits, biochemical composition, and enzymatic features of both variants [45]. In 2014, Shnain and colleagues [46] obtained a higher number of leaves in tomatoes at a combined concentration application of Zn (1250 ppm) and B (1250 ppm).

The greatest plant height (106.9 cm), quantity of leaves per plant (68.9), surface area of the leaf (48.2 cm^2), number of clusters per plant (21.6), number of branches per plant (11.9), number of fruits per cluster (1.8), amount of fruits per plant (33.6), fruit length (5.3 cm) and diameter (5.1 cm), fruit weight ($60.4 \text{ g fruit}^{-1}$), and yield ($1.9 \text{ kg plant}^{-1}$, $25.7 \text{ kg plot}^{-1}$ and 58.3 t ha^{-1}) were also reported for the combined application of foliar spray with 12.5 ppm ZnSO_4 and 12.5 ppm H_3BO_3 , whereas the lowest outcomes were observed in the control group [47]. Ullah et al. [48] also reported that the number of flower-bunches per plant (27.45), number of flowers per bunch (5.66), number of fruits per bunch (4.57), number of branches per plant (7.36), and yield (23.40 t ha^{-1}) of tomato had maximum outcomes with an application of 0.4% Zn foliar spray. Singh and Tiwari [49] also observed an increasing number of tomato-plant leaves with the foliar application of Zn and B. The use of Zn and B together also can increase the number of tomatoes per plant [50]. The foliar application of Zn (50 ppm) can enlarge the length of roots at 105 days in tomatoes [51]. It was found that the vegetative and reproductive growths of tomatoes were significantly enhanced by the combined application of Fe (200 mg L^{-1}) and Zn (100 mg L^{-1}). The combination resulted in the plant's maximum height (124.14 cm), branches per plant (8.36), per-cluster flower count (18.14), per-cluster fruits count (8), numbers of fruits per plant (90.14), the average weight of fruits (95.14 g), SPAD guided chlorophyll content ($22.14 \mu\text{mol}$), and yield (25.14 t ha^{-1}) [52].

A field experiment was conducted by Naga Sivaiah et al. [53] for measuring the influence of the foliar application of micronutrients in two tomato varieties: Utkal Kumari and Utkal Raja on vegetative and reproduction growth attributes. The maximal growth

of the plant (85.7%) was observed 30 days to 70 days after transplantation, following the application of a blend of micronutrients (78.2%) with 100 ppm foliar treatment, including B, Zn, molybdenum (Mo), copper (Cu), Fe, manganese (Mn), and B foliar application (77.5%) at 100 ppm.

Datta Reddy et al. [54] experimented with the outcome of foliar application of six micronutrients (Zn, Mo, B, Cu, Mn, and Fe) on growth and yield parameters in two tomato varieties (e.g., Arkasourabh and Arkavikas). They found that mixed application of all micronutrients (250 ppm) except Mn (50 ppm) showed better plant growth patterns in terms of plant height, the number of compound leaves, and yield parameters (e.g., tender and mature fruits per plant) over the control samples.

Saravaiya and co-workers [55] experimented on the effect of the foliar spray application of micronutrients on tomato (*Lycopersicon esculentum* Mill. var. Gujarat Tomato 2) plants. They demonstrated significant results in terms of plant height (132.77 cm), the garden-fresh weight of foliage (25.70 t ha⁻¹), quantity of branches per plant (5.96), dry matter yield of plants (7669.04 kg ha⁻¹), the maximum number of days before the last harvest (166.01), quantity of fruits per plant (34.43), length of fruits (5.47 cm), fruit diameter (4.57 cm), fruit volume (65.94 cm³), the weight of a single fruit (49.00 g), per-plant fruit weight (1.69 kg), thickness of the pericarp (6.27 mm), quantity of locules per fruit (3.01), fruit yield (46.87 t ha⁻¹), and saleable fruit yield per hectare (45.68 t) with the usage of N (75 kg ha⁻¹), P (as P₂O₅, 37.5 kg ha⁻¹), K (as K₂O, 62.5 kg ha⁻¹) as a combination of chemical fertilizers along with 100 ppm of Zn.

Dixit et al. [17] also reported another experiment and best outcomes after the combined foliar application of FeSO₄ (0.2%), CaNO₃ (0.2%), B (0.1%), and ZnSO₄ (0.2%) spray in terms of maximum plant height, plant girth, the number of fruits per plant, fruit length and diameter, fruit weight, and per-plant yield compared to the control group of plants. Various researchers found Zn significantly influences different parameters, which are mentioned in the following Table 1.

Table 1. Influence of Zn on different parameters.

No.	Parameters	Results	References
1	The plant height	86.53 cm and 105.25 cm @ 0.5% and 0.2% ZnSO ₄ , and 124.14 cm and 132.77 cm @ 100 ppm	[13,17,44,47,52–55]
2	Number of primary per plant	2.53 @ 0.5% ZnSO ₄	[44]
3	Number of secondary per plant	6.42 @ 0.5% ZnSO ₄	[44]
4	Leaf area	63.33 cm ² @ 0.5% ZnSO ₄	[44,47]
5	Number of leaves per plant	167 @ 0.5% ZnSO ₄	[44,46,47,49,54]
6	Number of fruits per plant	63.78, 72.07 @ 0.5%, 0.2% ZnSO ₄ respectively, and 34.43, 90.14 @ 100 ppm	[44,47,50,52,55]
7	Individual fruit weight	80.06 g @ 0.2% ZnSO ₄ , 49.0 g, 95.14 g @ 100 ppm	[17,52,55]
8	Chlorophyll content	22.14 µmol	[52]
9	Fruit length and diameter	4.77 cm and 4.57 cm @ 0.2% ZnSO ₄ and 5.47 cm and 4.57 cm @ 100 ppm	[17,55]
10	Pericarp thickness	6.27 mm @ 100 ppm	[55]
11	Number of branch per plant	7.36 @ 0.4% ZnSO ₄ and 8.36, 5.96 @ 100 ppm	[48,52,55]
12	Dry matter yield	7.67 t ha ⁻¹ @ 100 ppm	[55]
13	Fruit yield	23.40 t ha ⁻¹ @ 0.4% ZnSO ₄ and 25.14, 46.87 t ha ⁻¹ @ 100 ppm	[45,47,48,52,55]
14	Number of flowers per cluster	18.14 @ 100 ppm	[52]
15	Number of fruit per cluster	8.0 @ 100 ppm	[47,52]
16	Number of flowers per bunch	5.66 @ 0.4% ZnSO ₄	[48]
17	Number of fruit per bunch	4.57 @ 0.4% ZnSO ₄	[48]
18	Number of flower-bunch per plant	27.45 @ 0.4% ZnSO ₄	[48]

6. Effect of ZnO-NPs on Tomato Production

Nanoparticles are made from organic and inorganic nanomaterials. Their synthesis also varies in terms of physical or chemical methods. The inorganic nanomaterials include the metal oxides, such as ZnO, TiO₂, MgO, and AgO, and others. On the other hand, the organic nanomaterials include lipids, polymers, and carbon nanotubes. Nanoparticles of different materials are usually four types, i.e., silver, gold, alloy, and magnetic. In this regard, nanofertilizers are classified on the basis of nutrient categorization. Therefore, there are classically two types of nanofertilizers, i.e., micronutrient nanofertilizers and macronutrient nanofertilizers [56]. The components of nanofertilizers may include zinc oxide nanoparticles (ZnO-NPs), silica, iron, and titanium dioxide, ZnS/ZnCdSe core-shell quantum dots (QDs), InP/ZnS core-shell QDs, Mn/ZnSeQDs, gold nanorods, Al₂O₃, TiO₂, CeO₂, and FeO [57]. These nanofertilizers are synthesized following the specific method from the respective chemicals. For example, Zn nanofertilizers are synthesized from ZnO, and Fe nanofertilizers are synthesized from Fe₂O₃.

Recently, researchers have observed the effects of nanoparticles of zinc oxide, Zn-NPs, on various crops, including tomatoes. The acceptance of nanoparticles by plants is influenced by various factors, such as the nature of the particles as well as the interaction of NPs with the environment and the physiological condition of the plant (Figure 2).

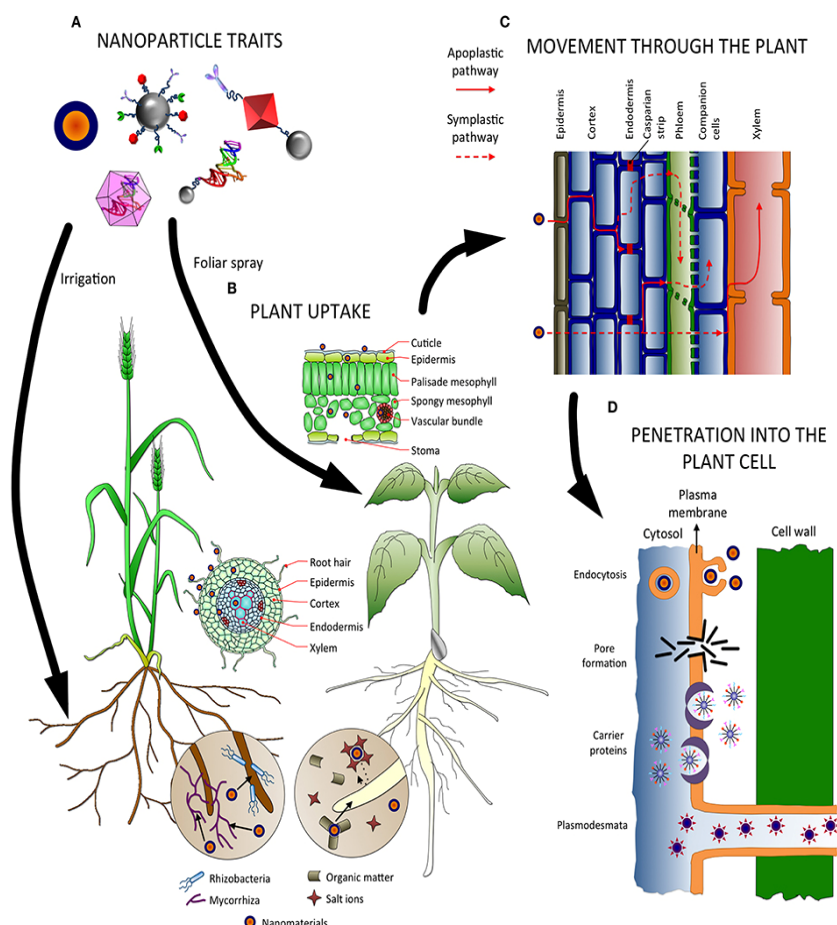


Figure 2. Factors influencing absorption, uptake, transport, and penetration of nanoparticles in plants. (A) Nanoparticle traits affect how they are taken up and translocated in the plant, as well as the application method. (B) In the soil, nanoparticles can interact with microorganisms and compounds, which might facilitate or hamper their absorption. Several tissues (epidermis, endodermis) and barriers (Casparian strip, cuticle) must be crossed before reaching the vascular tissues, depending on the entry point (roots or leaves). (C) Nanomaterials can follow the apoplastic and/or the symplastic pathways for moving up and down the plant and radial movement for changing from one pathway to the other. (D) Several mechanisms have been proposed for the internalization of nanoparticles inside the cells, such as endocytosis, pore formation, mediated by carrier proteins, and through plasmodesmata [58].

The effects of different Zn and ZnO-NPs concentrations in tomatoes and wheat were evaluated by Amooaghaie et al. [59]. Results showed that Zn and ZnO-NPs help in germinating seeds and boosting growth parameters at lower concentrations, while NPs decrease these characteristics at higher concentrations. However, dissolved zinc ($3\text{--}23\text{ mg L}^{-1}$) to form NPs had no significant impact on either of the species' germination factors. Among different concentrations of ZnO-NPs, foliar spraying at 50 ppm gave the maximum result in the case of shoot length (30.1%), shoot fresh mass (27.7%), shoot dry mass (29.0%), root length (28.7%), root fresh mass (26.1%), root dry mass (24.6%), and leaf area (24.1%), SPAD chlorophyll content (32.1%), the fruit number per plant (21.1%), and fruit yield (19.4%) over control [36]. Rosa and co-workers [60] presented that the germination percentage was reduced by 20% with the application of ZnO-NPs (1600 mg L^{-1}) over control, and root growth of seedling also decreased by 50% with the application of 800 and 1600 mg L^{-1} of ZnO-NPs over control. On the other hand, seedling increased the biomass production by 35% over control when seeds were germinated with 800 mg L^{-1} .

Tomato seeds responded variably towards the treatment at different concentrations of ZnO-NPs. Seed treated with the application of 400 ppm ZnO-NPs recorded significant germination (93.33%) and Seedling Vigor Index (919.80). Actually, the application of 400 ppm ZnO-NPs represented the maximum result, and after that, higher concentrations showed decreased seedling vigor index [61].

Zinc oxide nanoparticles have a positive impact on salt tolerance. Hosseinpour et al. [62] reported that the application of ZnO-NPs at 40 ppm could be mitigated salinity stress in tomato seedlings. They mentioned that the flag leaf width, plant height, stem diameter, leaf fresh weight, leaf dry weight, root fresh weight, and root dry weight found higher values in salinity stress with the application of 40 mg L^{-1} ZnO-NPs with *Lactobacillus casei* and the lowest results of that were recorded under 250 mM NaCl stress (Figure 3).



Figure 3. Treated tomato seedlings (a) Control, (b) ZnO-NPs, (c) *Bacillus pumilis* (N1), (d) *Bacillus pumilis* (N1) + 20 mg L^{-1} ZnO-NPs, (e) *Bacillus pumilis* (N1) + 40 mg L^{-1} ZnO-NPs.

The maximum number of flowers was recorded by applying foliar spraying@ 250 ppm ZnO-NPs over control which indicates that the foliar spraying could be used as an effective way to deliver nutrients to plants. These nanoparticles also produced 81.9% more tomato fruit (by weight) than the control at 66 days after the seeding of tomato [63]. Tomato plants that were treated with hexagonal morphology and superficially modified ZnO-NPs had significantly enhanced plant height, stem diameter, and plant organs (leaves, stem, and root) dry weights [64].

The results from a group of researchers revealed that foliar spraying of ZnO-NPs significantly increased shoot length (SL) and root length (RL), biomass, leaf area, chlorophyll content, and photosynthetic attributes of tomato plants in the presence of salt stress. Moreover, the application of ZnO-NPs mitigated the negative impacts of salt stress on tomato growth and enhanced protein content under salt stress. Therefore, ZnO-NPs may

be used to enhance the growth performance and mitigate the unfavorable effects of NaCl in the tomato plant [65].

There are also several effects of ZnO-NPs on other crops. Many studies have shown that ZnO-NPs can improve plant growth and development in peanut and onion but that ZnO-NPs have an advantageous effect on seed germination at low ZnO concentration [66,67]. Thunugunta et al. [68] discovered that ZnO-NPs had no toxic impact on plant growth characteristics in the soil medium but rather increased plant growth of eggplant. They also found that shoot length, leaf length, and leaf width, along with plant mass was shown to be a little bit responsive at a lower concentration of ZnO-NPs, 5 mg kg⁻¹. However, these specifications improved with increasing ZnO-NPs concentrations up to 15 mg kg⁻¹ and then declined with subsequent applications of further ZnO-NPs, such as 20 and 100 mg kg⁻¹.

The results of tomato plants after applying similar doses of nano fertilizers and regular fertilizers are presented in the following table (Table 2).

Table 2. Comparing the results of nanofertilizers and regular fertilizers when applying similar doses of nutrients.

Doses	Impact of Nano Fertilizer	Impact of Regular Fertilizer	References
50 ppm (ZnSO ₄ and ZnO-NPs)	The increased root and shoot length, shoot dry matter, number of fruit per plant, chlorophyll content	Enlarged length of the root	[36,51]
100 ppm (ZnSO ₄ and ZnO-NPs)	Enhanced photosynthetic attributes and non-enzymatic antioxidants, increased sucrose, starch, and glucose	Increased plant height, dry matter yield, number of fruits per plant, individual fruit weight, pericarp thickness, chlorophyll content	[52,53,55,69,70]
250 ppm (ZnSO ₄ and ZnO-NPs)	Increased fruit yield by 81.9 percent	Increased plant growth, number of leaves, fruit per plant	[54,63]
350–400 ppm (ZnSO ₄ and ZnO-NPs)	Increased germination and seedling vigor index significantly	Highest plant height	[48,61]

7. Impact of Zinc Sulfate Fertilizer on Tomato Crops' Nutritional Quality

Crops require nutrients in order to grow and produce at a high level. Fertilizers and micronutrients help crop nutrition by identifying crops that are well-adapted to low soil fertility or are particularly efficient at utilizing nutrients. Improved crop nutrient management can boost macro- and micronutrient bioavailability in crops and grains, which is essential for optimal crop growth and yield quantity and quality. Essential nutrients, along with water, sunshine, and favorable soil conditions, are important for improving crop production and plant resistance to climate change [71].

Singh et al. [39] obtained the maximum numbers of fruit per cluster (28.22, 30.33, and 32.80), percentage of fruit set (57.84%, 77.78%, and 85.76%), average fruit weight (14.87 g), number of fruit per plant (244.15), fruit yield per plant (4.98 kg), the yield of fruits (4.98 t/ha), higher TSS (13.1 °Brix), vitamin C (14.10 mg/100 g fruit pulp) with the combined treatment of B (2.0 g/L) and Zn (2.0 g/L). It was observed from the experiment of Ejaz et al. [72] that the foliar application of Zn (6%), B (5%), and N (2%), individually, showed better results over the control group, but the total soluble solids (TSS), titratable acidity, and vitamin C content presented extraordinary results in the case of their combined approach (i.e., Zn = 6%, B = 5%, N = 2%).

Gurmani and colleagues [45] noticed that the application of Zn (10–15 mg kg⁻¹) considerably enhanced superoxide dismutase and peroxidase catalase activity in fruits of tomato. Meena et al. [73] observed significant results in the quality parameters of tomatoes. They found that the maximum pericarp thickness, ascorbic acid content, percentage of total sugar, and reducing sugar and non-reducing sugar were recorded by the application of 100 ppm zinc along with boron.

In 2017, Chand and Prasad [74] documented the maximum diameter and dry matter of fruits after the application of B, ZnSO₄, and CuSO₄ at 100 ppm level as compared to the control as well as other treatments. The TSS in tomato fruits were maximum (5.82 °Brix and

5.54 °Brix) under a combined spray of 250 ppm of B, Zn, and Cu. The maximum increase in the ascorbic acid content of tomato fruits (25.29 mg100⁻¹ g and 24.41 mg100⁻¹ g) was recorded with the application of Zn, B, and Cu at 250 ppm, which has accounted for a 62.39% increase (14.45 mg100⁻¹ g and 13.78 mg100⁻¹ g) compared to the control.

The highest TSS (5.87 °Brix), fruit firmness (3.66 kg cm⁻²), titratable acidity (4%), pH (2.61%), and fruit lycopene content (2.25 mg100⁻¹ g) were observed when tomato plants were treated with a combined foliar spray consisting of Zn (100 mg L⁻¹) and Fe (200 mg L⁻¹) [52]. Swetha et al. [75] discovered that the combination of different micronutrients was influenced the quality parameters of tomatoes. The maximum TSS (5.03 °Brix) juiciness of tomato (31.24%), acidity (1.06%), and ascorbic acid (26.67 mg/100 g of fruit juice) were found by the application of zinc sulfate @ 500 ppm along with boron, iron, and copper. Salam and colleagues [76] presented that the combined application of B, Zn, and cow dung at 2.5 kg ha⁻¹, 6 kg ha⁻¹, and 20 t ha⁻¹, respectively, could achieve improved pulp weight (90.24%), dry matter content (5.82%), amount of lycopene (147 µg100⁻¹ g), ascorbic acid (11.2 mg100⁻¹ g), chlorophyll-a (42.0 µg100⁻¹ g), chlorophyll-b (61.0 µg100⁻¹ g), B (36 µg g⁻¹), Zn (51 µg g⁻¹) as well as an increased amount of saleable fruits at 30 days after storage (74%) and better shelf-life (17 days).

Similarly, zinc sulfate fertilizer has a significant impact on the nutritional quality of other crops. The application of ZnSO₄ can also increase the TSS level in guava fruit [77]. Additionally, Singh and co-workers reported that the weight and number of the raceme, TSS, and the juice content of grapevine were increased with the application of ZnSO₄ [78]. When a Zn (0.8%) and B (0.8%) mixture was applied on the Cape Goose Berry tree, fruit quality was improved by increased acidity, TSS, ascorbic acid content compared to the control [79].

It was found in one of the experiments by Kazemi and co-workers [80] that different applied treatments significantly corresponded to higher vegetative growth and fruit quality in cucumber plants. According to the findings, Zn (50 mg L⁻¹) and Fe (100 mg L⁻¹) increased chlorophyll content and yield. The effect of Zn and Fe was positive, with major increases in fruit quality, at 50 mg L⁻¹ and 100 mg L⁻¹ of Zn and Fe, respectively.

8. Effect of ZnO-NPs on the Nutritional Quality of Tomato

ZnO-NPs have potential effects on promoting agricultural productivity. The effect of NPs on crops varies with the species and age as well as doses and characteristics of the NPs. ZnO-NPs lessened the effects of NaCl by the accumulation of superoxide dismutase (SOD) and glutathione peroxidase (GPX) in tissues of tomatoes, and a lower concentration (15 mg L⁻¹) is more effective than a higher concentration (30 mg L⁻¹) for tomato plants [81]. Wang and colleagues [12] also demonstrated in their experiment that ZnO-NPs boosts the antioxidant activities of enzymes and the transcriptions process of relevant genes, and these NPs only had a toxic effect on tomato plants at higher concentrations (e.g., 400 and 800 mg dm⁻³) but at low concentrations (upto 200 mg dm⁻³) there was no detrimental effect on plant growth.

The foliar spraying of ZnO-NPs gave a significant response in the case of nutritional quality parameters of tomato. The maximum activity of catalase (60%), peroxidase (74%), and superoxide dismutase (55%) were recorded in the plant to which 50 ppm of ZnO-NPs was applied. On the other hand, fruits grown from ZnO-NPs treated plants had a higher content of lycopene and β-carotene as compared to control plants. The maximum results were also found in the case of lycopene (23%) and β-carotene (25%) content with treatment at 50 ppm ZnO-NPs [36]. The total soluble solids were increased by 26.92% with the application of phytonanoparticles at 50 ppm over control [82]. The maximum activity of different enzymes was noted in the plants treated with ZnO-NPs at 8 mg L⁻¹ for 30 min. The activity of CAT increased by 69.7%, POX by 65.0%, and SOD by 80% compared with the control plants [83].

A group of researchers investigated the effects of ZnO-NPs on tomato growth indices and antioxidant defense system activity under tomato mosaic tobamovirus (ToMV) stress.

The application with 100 ppm ZnO-NPs showed remarkably increased growth indices, photosynthetic attributes, and enzymatic and non-enzymatic antioxidants, which may be a hopeful strategy to overcome ToMV infections [69]. Lycopene, an antioxidant, is an important nutritional parameter in tomato fruits. The lycopene content was increased by 113.1% in fruits obtained from plants treated with 100 ppm ZnO nanoparticles by foliar application [63]. The application of ZnO-NPs mitigates the negative impacts of salt stress on tomato growth and enhances protein content and antioxidative enzyme activity, such as peroxidase (POX), superoxide dismutase (SOD), and catalase (CAT) under salt stress [66].

Foliar spraying with ZnO-NPs @ 100 ppm increased the levels of sucrose, starch, and glucose in tomato plants [70].

ZnO-NPs has a significant influence another crops. It was reported that the application of zinc nano fertilizer enhances enzyme activities of acid phosphatase (76.9%), alkaline phosphatase (61.7%), phytase (322.2%), and dehydrogenase (21%) were observed over control. These phosphorous mobilizing enzymes assist in the mobilization of native phosphorous existing in the rhizosphere in the complex form with calcium, iron, or aluminum [84]. Compared to control, the electrolyte leakage (EL) was reduced in both shoots and roots with the application of ZnO-NPs than control in wheat [11]. Nanoparticles had significantly enhanced the superoxide dismutase (SOD) and peroxidase (POD) activities in wheat leaves. With the application of 100 mg L⁻¹ ZnO-NPs, the SOD and POD activities increased by 47% and 50%, respectively, over the control [85]. The seed treatment and Zn-source concentration significantly affected the plant quality parameters of the fodder maize crop. The application of ZnO-NPs (at 40 mg L⁻¹ concentration) exhibited significantly higher neutral detergent fiber (NDF) and cellulose content as compared to control [86].

The impact of fertilizers on tomatoes and other crops is mentioned in the following Table 3.

Table 3. Impact of fertilizers on tomato production.

Fertilizer Used	Concentration	Time of Application	Exposure Methodology	Impact	References
ZnSO ₄	350 ppm	40, 50, and 60 days after transplanting (DAT)	Foliar spray	Increased plant height	[13]
ZnSO ₄	2000 ppm	15 and 21 DAT	Foliar spray	Increased quantity of fruits	[17]
ZnSO ₄	5000 ppm	Pre flowering and fruit setting stage	Foliar spray	Increased leaf area	[44]
ZnSO ₄	10 ppm	Before transplanting	Soil media	Enhanced fruit yield	[45]
ZnSO ₄	1250 ppm	Pre flowering and fruit setting stage	Foliar spray	Maximum number of leaves/plant	[46]
ZnSO ₄	4000 ppm	Pre flowering and fruit setting stage	Foliar spray	Improved number of fruits	[48]
ZnSO ₄	100 ppm	30 DAT and fruit became berry sized	Foliar spray	Maximum plant height	[52]
ZnSO ₄	100 ppm	30, 40, and 50 DAT	Foliar spray	Enhanced growth of plant and fruit yield	[53]
ZnSO ₄	100 ppm	40, 50, and 60 DAT	Foliar spray	Enhanced the dry matter yield of plant	[55]
ZnO-NPs	400 ppm	30 days after sowing(DAS)	Foliar spray	Increased significant Seedling vigor Index	[61]
ZnO-NPs	40 ppm	Rhizosphere area of the plant in pots by injection (20 mL) twice a week	Foliar spray	Enhanced early flowering and plant growth	[63]
ZnO-NPs	250 ppm	14th day of plant growth	Foliar spray	Increased fruit weight	[64]
ZnO-NPs	100 ppm	25 and 35 DAT	Foliar spray	Mitigated the negative impact of salt stress	[66]

9. Conclusions

According to the data presented above, it has been confirmed that there is a notable positive trend toward the commercialization of a new Zn and ZnO-NPs foliage fertilizer on tomato production. The foliar application of Zn has a vast influence on the tomato plant.

The maximum numbers of fruit per cluster, percentage of fruit set, individual fruit weight, the quantity of fruit per plant, fruit yield per plant, chlorophyll content, higher TSS, vitamin C, and lycopene content were observed after the application of Zn spray. For optimizing crop activities to foliage nutrient sprays, more studies on foliar fertilization of tomato crops must be conducted in the coming future. Such types of experiments may incorporate the foliar application of Zn fertilizer as an effective tool and create environmentally friendly tomato production. On the other hand, nanotechnology also contributes to enhancing crop yields by improving fertilizer use efficiencies. The NPs articulate their distinctive features by being smaller, having highly defined outside areas, potential surface energy, and high solubility. Due to these unique properties, plant uptake is increased. Therefore, nanotechnology can be used in agriculture to supply agrochemicals quickly to the site of exploitation with only slight depletion. Due to their diverse properties, functionalities, and applications, NPs are one of the most multipurpose materials. Application of ZnO-NPs to crops can stimulate their growth, yield, and quality. Nutrient demand in food is increasing progressively, but the yield of tomato crops is gradually declining. Therefore, to achieve food demand and improve food quality, it is essential to become familiar with foliar application of Zn nutrient and ZnO-NPs for sustainable agriculture.

Author Contributions: R.A. wrote the first draft and incorporated the input from the reviews. M.Y.A.S., M.K.U., M.A.Q. and M.A.M.H. reviewed the draft and improved the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Agricultural Technology Program Phase-II, Bangladesh Agricultural Research Council (BARC), Bangladesh.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors are grateful to the Ministry of Agriculture, Bangladesh, the Bangladesh Agricultural Research Institute (BARI) and the Bangladesh Agricultural Research Council (NATP Phase-II Project, BARC for providing financial support.

Conflicts of Interest: The authors declare that there is no conflict of interest.

References

1. Olaniyi, J.O.; Akanbi, W.B.; Adejumo, T.A.; Akande, O.G. Growth, fruit yield and nutritional quality of tomato varieties. *Afr. J. Food Sci.* **2010**, *4*, 398–402.
2. Mohamed, A.N.; Ismail, M.R.; Rahman, M.H. In vitro response from cotyledon and hypocotyls explants in tomato by inducing 6-benzylaminopurine. *Afr. J. Biotechnol.* **2010**, *9*, 4802–4807.
3. Srividya, S.; Reddy, S.S.; Sudhavani, V.; Reddy, R. Effect of post-harvest chemicals on fruit physiology and shelf life of tomato under ambient conditions. *Int. J. Agric. Food Sci. Technol.* **2014**, *5*, 99–104.
4. Broadley, M.R.; White, P.J.; Hammond, J.P.; Zelko, I.; Lu, A. Zinc in plants. *New Phytol.* **2007**, *173*, 677–702. [[CrossRef](#)]
5. Jain, R.; Srivastava, S.; Solomon, S.; Shrivastava, A.K.; Chandra, A. Impact of excess zinc on growth parameters, cell division, nutrient accumulation, photosynthetic pigments and oxidative stress of sugarcane (*Saccharum* spp.). *Acta Physiol. Plant.* **2010**, *32*, 979–986.
6. Sbartaï, H.; Djebbar, M.R.; Rouabhi, R.; Sbartaï, I.; Berrebbah, H. Antioxidative response in tomato plants *Lycopersicon esculentum* L. roots and leaves to Zinc. *Am.-Eurasian J. Toxicol. Sci.* **2011**, *3*, 41–46.
7. Adams, P. Effect of nutrition on tomato quality, tomatoes in peat. How feed variations affect yield. *Grower* **2004**, *89*, 1142–1145.
8. Rico, C.M.; Majumdar, S.; Duarte-Gardea, M.; Peralta-Videa, J.R.; Gardea-Torresdey, J.L. Interaction of nanoparticles with edible plants and their possible implications in the food chain. *J. Agric. Food Chem.* **2011**, *59*, 3485–3498.
9. Nel, A.; Xia, T.; Mädlar, L.; Li, N. Toxic potential of materials at the nanolevel. *Science* **2006**, *311*, 622–627. [[PubMed](#)]
10. Khodakovskaya, M.V.; de Silva, D.; Biris, A.S.; Dervishi, D.; Villagarcia, H. Carbon nanotubes induce growth enhancement of tobacco cells. *ACS Nano* **2012**, *6*, 2128–2135. [[CrossRef](#)]
11. Munir, T.; Rizwan, M.; Kashif, M.; Shahzad, A.; Ali, S.; Amin, N.; Zahid, R.; Alam, M.F.E.; Imran, M. Effect of zinc oxide nanoparticles on the growth and Zn uptake in wheat (*Triticum aestivum* L.) by seed priming method. *Dig. J. Nanomater. Bios.* **2018**, *13*, 315–323.

12. Wang, X.P.; Li, Q.Q.; Pei, Z.M.; Wang, S.C. Effects of zinc oxide nanoparticles on the growth, photosynthetic traits, and antioxidative enzymes in tomato plants. *Biol. Plant.* **2018**, *62*, 801–808. [\[CrossRef\]](#)
13. Harris, K.D.; Mathuma, V. Effect of foliar application of boron and zinc on growth and yield of tomato (*Lycopersicon esculentum* Mill.). *Asian J. Pharm. Sci. Technol.* **2015**, *5*, 74–78.
14. Hatwar, G.P.; Gondane, S.U.; Urkude, S.M.; Gahukar, O.V. Effect of micronutrients on growth and yield of chilli. *Soil Crops* **2003**, *13*, 123–125.
15. Nawaz, H.; Zubair, M.; Derawadan, H. Interactive effects of nitrogen, phosphorus and zinc on growth and yield of Tomato (*Solanum lycopersicum*). *Afr. J. Agric. Res.* **2012**, *7*, 3792–3799.
16. Sultana, S.; Naser, H.M.; Akhter, S.; Begum, R.A. Effectiveness of soil and foliar applications of zinc and boron on the yield of tomato. *Bangladesh J. Agril. Res.* **2016**, *41*, 411–418. [\[CrossRef\]](#)
17. Dixit, A.; Sharma, D.; Sharma, T.K.; Bairwa, P.L. Effect of foliar application of some macro and micronutrients on growth and yield of tomato (*Solanum lycopersicum* L.) cv. ArkaRakshak. *Int. J. Curr. Microbiol. App. Sci.* **2018**, *6*, 197–203.
18. Mahajan, P.; Dhoke, S.K.; Khanna, A.S.; Tarafdar, J.C. Effect of nano-ZnO on growth of mung bean (*Vignaradiata*) and chickpea (*Cicer arietinum*) seedlings using plant agar method. *Appl. Biol. Res.* **2011**, *13*, 54–61.
19. Al-Amri, S.M. Improved growth, productivity and quality of tomato (*Solanum lycopersicum* L.) plants through application of shikimic acid. *Saudi J. Biol. Sci.* **2013**, *20*, 339–345. [\[CrossRef\]](#)
20. Ejaz, M.; Rehman, S.U.; Waqas, R.; Manan, A.; Imran, M.; Bukhari, M.A. Combined efficacy of macronutrients and micro-nutrients as a foliar application on growth and yield of tomato grown by vegetable forcing. *Int. J. Agron. Vet. Med. Sci.* **2011**, *5*, 327–335.
21. Willcox, J.K.; Catignani, G.L.; Lazarus, S. Tomatoes and cardiovascular health. *Crit. Rev. Food Sci. Nutr.* **2003**, *43*, 1–18. [\[CrossRef\]](#) [\[PubMed\]](#)
22. Chapagain, P.B.; Wiesman, Z. Effect of potassium magnesium chloride in the fertigation solution as partial source of potassium on growth, yield and quality of greenhouse tomato. *Sci. Hortic.* **2004**, *99*, 279–288. [\[CrossRef\]](#)
23. Abdel-Monaim, M.F. Induced systemic resistance in tomato plants against Fusarium wilt diseases. *Inter. Res. J. Microbiol.* **2012**, *3*, 14–23.
24. Canene-Adams, K.; Campbell, J.K.; Zaripheh, S.; Jeffery, E.H.; Erdman, J.W. The tomato as a functional food. *J. Nutr.* **2005**, *135*, 1226–1230. [\[CrossRef\]](#)
25. Tahir, A.; Shah, H.; Sharif, M.; Akhart, W.; Akmal, N. An overview of tomato economy of Pakistan: Comparative analysis. *Pakistan J. Agric. Res.* **2012**, *25*, 288–294.
26. Wijnands, J. The international competitiveness of fresh tomatoes, peppers and cucumbers. *Acta Hortic.* **2003**, *611*, 79–90. [\[CrossRef\]](#)
27. Foliar Recommendations. Available online: <https://icl-sf.com/global-en/article/recommendations-for-efficient-foliar-application> (accessed on 4 September 2021).
28. The Advantages of Foliar Fertilization. Available online: <https://chelal.com/en/goals/advantages-foliar-fertilisation> (accessed on 4 September 2021).
29. Drobek, M.; Frac, M.; Cybulska, J. Plant Biostimulants: Importance of the Quality and Yield of Horticultural Crops and the Improvement of Plant Tolerance to Abiotic Stress—A Review. *Agronomy* **2019**, *9*, 335. [\[CrossRef\]](#)
30. Narimani, H.; Rahimi, M.M.; Ahmadihah, A.; Vaezi, B. Study on the effects of foliar spray of micronutrient on yield and yield components of durum wheat. *Arch. Appl. Sci. Res.* **2010**, *2*, 168–176.
31. Bozoglu, H.; Ozcelik, H.; Mut, Z.; Pesken, E. Response of chickpea (*Cicerarientinum* L.) to zinc and molybdenum fertilization. *Bangladesh J. Bot.* **2007**, *36*, 145–149. [\[CrossRef\]](#)
32. Kinaci, E.; Gulmezoglu, N. Grain yield and yield components of triticale upon application of different foliar fertilizers. *Interciencia* **2007**, *32*, 624–628.
33. Ali, S.; Khan, A.Z.; Mairaj, G.; Arif, M.; Fida, M.; Bibi, S. Assessment of different crop nutrient management practices for yield improvement. *Austr. J. Crop. Sci.* **2008**, *2*, 150–157.
34. Aghtape, A.A.; Ghanbari, A.; Sirousmehr, A.; Siahars, B.; Asgharipour, M.; Tavssoli, A. Effect of irrigation with wastewater and foliar fertilize application on some forage characteristics of foxtail millet (*Setariaitalica*). *Int. J. Plant. Physiol. Biochem.* **2011**, *3*, 34–42.
35. Ali, S.; Javed, H.U.; Rehman, R.N.U.; Sabir, I.A.; Naeem, M.S.; Siddiqui, M.Z.; Saeed, D.A.; Nawaz, M.A. Foliar application of some macro and micro nutrients improves tomato growth, flowering and yield. *Int. J. Biosci.* **2013**, *3*, 280–287.
36. Faizan, M.; Hayat, S. Effect of foliar spray of ZnO-NPs on the physiological parameters and antioxidant systems of *Lycopersicon esculentum*. *Pol. J. Natur. Sci.* **2019**, *34*, 87–105.
37. Patil, B.C.; Hosamni, R.M.; Ajappalavara, P.S.; Naik, B.H.; Smitha, R.P.; Ukkund, K.C. Effect of foliar application of micronutrients on growth, yield components of Tomato (*Lycopersicon esculentum* Mill.). *Karnataka J. Agri. Sci.* **2008**, *21*, 428–430.
38. Alloway, B.J. Fundamental aspects of zinc in soils and plants. In *Zinc in Soils and Crop Nutrition*, 2nd ed.; IZA: Brussels, Belgium; IFA: Paris, France, 2008; pp. 30–52.
39. Singh, B.; Kasera, S.; Mishra, S.K.; Roy, S.; Rana, S.; Singh, D. Growth, yield and quality of cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*) as influenced by foliar application of Zinc and Boron. *J. Pharmacogn. Phytochem.* **2017**, *SPI*, 911–914.
40. Abedy, A. Effects of Zinc Sulfate and Citric Acid Spray on Fruit Characteristics of Tomato Cultivar ‘Urbana’. Master’s Thesis, Shiraz University, Shiraz, Iran, 2001.

41. Sardar, H.; Naz, S.; Ejaz, S.; Rarooq, O.; Rehman, A.U.; Javed, M.S.; Akhtar, G. Effect of foliar application of zinc oxide on growth and photosynthetic traits of cherry tomato under calcareous soil conditions. *Acta Sci. Pol. Hortorum Cultus* **2021**, *20*, 91–99. [\[CrossRef\]](#)
42. Passam, H.C.; Karapanos, I.C.; Bebeli, P.J.; Savvas, D. A review of recent research on tomato nutrition, breeding and post-harvest technology with reference to fruit quality. *Eur. J. Plant. Sci. Biotechnol.* **2007**, *1*, 1–21.
43. Gopal, D.; Sarangthem, I. Effect of zinc on growth and yield of tomato (*Lycopersicon esculentum* cv. Pusa ruby). *Int. Curr. Res.* **2018**, *10*, 73616–73620.
44. Haleema, B.; Rab, A.; Hussain, S.A. Effect of calcium, boron and zinc foliar application on growth and fruit production of tomato. *Sarhad J. Agric.* **2018**, *34*, 19–30. [\[CrossRef\]](#)
45. Gurmani, A.R.; Din, J.U.; Khan, S.U.; Andaleep, R.; Waseem, K.; Khan, A.; Ullah, H. Soil Application of Zinc Improves Growth and Yield of Tomato. *Int. J. Agric. Biol.* **2012**, *14*, 91–96.
46. Shnain, R.S.; Prasad, V.M.; Saravanan, S. Effect of zinc and boron on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.) cv. HeemSohna, under protected cultivation. *Eur. Acad. Res.* **2014**, *2*, 4573–4597.
47. Ali, M.R.; Mehraj, H.; Jamal Uddin, A.F.M. Effects of foliar application of zinc and boron on growth and yield of summer tomato. *J. Biosci. Agric. Res.* **2015**, *6*, 512–517. [\[CrossRef\]](#)
48. Ullah, R.; Ayub, G.; Ilyas, M.; Ahmad, M.; Umar, M.; Mukhtar, S.; Farooq, S. Growth and Yield of Tomato (*Lycopersicon esculentum* L.) as Influenced by Different Levels of Zinc and Boron as Foliar Application. *Am.-Eurasian J. Agric. Environ. Sci.* **2015**, *15*, 2495–2498.
49. Singh, H.M.; Tiwari, J.K. Impact of micronutrient spray on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.). *Hort. Flora Res. Spectr.* **2013**, *2*, 87–89.
50. Yadav, P.V.S.; Tikkoo, A.; Sharma, N.K. Effect of Zn and B on growth, flowering and fruiting of tomato (*Lycopersicon esculentum* Mill.). *Haryana J. Hort. Sci.* **2001**, *30*, 105–107.
51. Vijayarengan, P.; Mahalakshmi, G. Zinc toxicity in tomato plants. *World Appl. Sci. J.* **2013**, *24*, 649–653.
52. Kazemi, M. Effects of Zn, Fe and their Combination Treatments on the growth and yield of tomato. *Bull. Env. Pharmacol. Life Sci.* **2013**, *3*, 109–114.
53. Naga Sivaiah, K.; Swain, S.K.; Varma, V.S.; Raju, B. Effect of Foliar Application of Micronutrients on Growth Parameters in Tomato (*Lycopersicon esculentum* mill.). *J. Agric. Food Sci.* **2013**, *1*, 146–151.
54. Datta Reddy, G.P.; Reddy, S.S.P.; Reddy, C.G.; Sivaram, T.G. Effect of foliar application of micronutrients on growth and yield parameters in tomato (*Solanum lycopersicum* L.). *Int. J. Pure App. Biosci.* **2018**, *6*, 929–934. [\[CrossRef\]](#)
55. Saravaiya, S.N.; Wakchaure, S.S.; Jadhav, P.B.; Tekale, G.S.; Patil, N.B.; Dekhane, S.S.; Patel, D.J. Influence of foliar application of micronutrients on tomato (*Lycopersicon esculentum* Mill.) cv. gujarat tomato-2. *Int. J. Dev. Res.* **2014**, *4*, 1539–1542.
56. Zulfiqar, F.; Navarro, M.; Ashraf, M.; Akram, N.A.; Bosch, S.M. Nanofertilizer use for sustainable agriculture: Advantages and limitations. *Plant Sci.* **2019**, *289*, 110270. [\[CrossRef\]](#)
57. Prasad, R.; Bhattacharyya, A.; Nguyen, Q.D. Nanotechnology in Sustainable Agriculture: Recent Developments, Challenges, and Perspectives. *Front. Microbiol.* **2017**, *8*, 1014. [\[CrossRef\]](#)
58. Pérez-de-Luque, A. Interaction of nanomaterials with plants: What do we need for real applications in agriculture? *Front. Environ. Sci.* **2017**, *5*, 12. [\[CrossRef\]](#)
59. Amooaghaie, R.; Norouzi, M.; Saeri, M. Impact of zinc and zinc oxide nanoparticles on the physiological and biochemical processes in tomato and wheat. *Botany* **2017**, *95*, 441–455. [\[CrossRef\]](#)
60. De la Rosa, G.; López-Moreno, M.L.; de Haro, D.; Botez, C.E.; Peralta-Videa, J.R.; Gardea-Torresdey, J. Effects of ZnO nanoparticles in alfalfa, tomato and cucumber at the germination stage: Root development and X-ray absorption spectroscopy studies. *Pure Appl. Chem.* **2013**, *85*, 2161–2174. [\[CrossRef\]](#)
61. Khanm, H.; Vaishnavi, B.A.; Shankar, A.G. Raise of Nano-Fertilizer Era: Effect of Nano Scale Zinc Oxide Particles on the Germination, Growth and Yield of Tomato (*Solanum lycopersicum*). *Int. J. Curr. Microbiol. App. Sci.* **2018**, *7*, 1861–1871. [\[CrossRef\]](#)
62. Hosseinpour, A.; Haliloglu, K.; Cinisli, K.T.; Ozkan, G.; Ozturk, H.I.; Aboughadareh, A.P.; Poczai, P. Application of Zinc Oxide Nanoparticles and Plant Growth Promoting Bacteria Reduces Genetic Impairment under salt Stress in Tomato (*Solanum lycopersicum* L. 'linda'). *Agriculture* **2020**, *10*, 521. [\[CrossRef\]](#)
63. Raliya, R.; Nair, R.; Chavalmame, S.; Wangab, W.N.; Biswas, P. Mechanistic evaluation of translocation and physiological impact of titanium dioxide and zinc oxide nanoparticles on the tomato (*Solanum lycopersicum* L.) plant. *Metallomics* **2015**, *7*, 1584–1594. [\[CrossRef\]](#)
64. Velasco, E.A.P.; Galindo, R.B.; Aguilar, L.A.V.; Fuentes, J.A.G.; Urbina, B.A.P.; Morales, S.A.L.; Valdés, S.S. Effects of the Morphology, Surface Modification and Application Methods of ZnO-NPs on the Growth and Biomass of Tomato Plants. *Molecules* **2020**, *25*, 1282. [\[CrossRef\]](#)
65. Faizan, M.; Bhat, J.A.; Chen, C.; Alyemeni, M.N.; Wijaya, L.; Ahmad, P.; Yu, F. Zinc oxide nanoparticles (ZnO-NPs) induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. *Plant Physiol. Biochem.* **2020**, *161*, 122–130. [\[CrossRef\]](#)
66. Prasad, T.N.V.K.V.; Sudhakar, P.; Sreenivasulu, Y.; Latha, P.; Munaswamy, V.; Reddy, K.R.; Sreeprasad, T.S.; Sajanlal, P.R.; Pradeep, T. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *J. Plant. Nutr.* **2012**, *35*, 905–927. [\[CrossRef\]](#)

67. Laware, S.L.; Raskar, S. Influence of Zinc Oxide Nanoparticles on Growth, Flowering and Seed Productivity in Onion. *Int. J. Curr. Microbiol. App. Sci.* **2014**, *3*, 874–881.
68. Thunugunta, T.; Reddy, A.C.; Seetharamaiah, S.K.; Hunashikatti, L.R.; Chandrappa, S.G.; Kalathil, N.C.; Reddy, L.; Reddy, D.C. Impact of Zinc oxide nanoparticles on eggplant (*S. melongena*): Studies on growth and the accumulation of nanoparticles. *Inst. Eng. Technol.* **2018**, *12*, 706–713. [\[CrossRef\]](#)
69. Sofy, A.R.; Sofy, M.R.; Hmed, A.A.; Dawoud, R.A.; Alnaggar, A.E.A.M.; Soliman, A.M.; Dougdoug, N.K.E. Ameliorating the Adverse Effects of Tomato mosaic tobamovirus Infecting Tomato Plants in Egypt by Boosting Immunity in Tomato Plants Using Zinc Oxide Nanoparticles. *Molecules* **2021**, *26*, 1337. [\[CrossRef\]](#)
70. Sun, L.; Wang, Y.; Wang, R.; Zhang, P.; Ju, Q.; Xu, J. Physiological, Transcriptomic and Metabolomic Analyses Reveal Zinc Oxide Nanoparticles Modulate Plant Growth in Tomato. *Environ. Sci. Nano* **2020**, *7*, 3587–3604. [\[CrossRef\]](#)
71. Improved Crop Nutrition. Available online: <https://www.iaea.org/topics/crop-nutrition> (accessed on 3 May 2021).
72. Ejaz, M.; Waqas, R.; Butt, M.; Rehman, S.U.; Manan, A. Role of macro-nutrients and micro-nutrients in enhancing the quality of tomato. *Int. J. Agron. Vet. Med. Sci.* **2011**, *5*, 401–404. [\[CrossRef\]](#)
73. Meena, D.C.; Maji, S.; Meena, J.K.; Kumawat, R.; Meena, K.R.; Kumar, S.; Sodh, K. Improvement of Growth, Yield and Quality of Tomato (*Solanum lycopersicum* L.) cv. Azad T-6 with Foliar Application of Zinc and Boron. *Int. J. Bio-Resour. Stress Manag.* **2015**, *6*, 598–601. [\[CrossRef\]](#)
74. Chand, T.; Prasad, V.M. Effect of Micronutrients Spray on Fruits Yield and Quality of Tomato (*Lycopersicon esculentum* Mill.). *Bull. Env. Pharmacol. Life Sci.* **2017**, *7*, 80–87.
75. Swetha, K.; Saravanan, S.; Banothu, L.N. Effect of micronutrients on fruit quality, shelf life and economics of tomato (*Solanum lycopersicum* L.) cv. Pkm-1. *J. Pharmacogn. Phytochem.* **2018**, *7*, 3018–3020.
76. Salam, M.A.; Siddique, M.A.; Rahim, M.A.; Rahman, M.A.; Goffar, M.A. Quality of tomato as influenced by boron and zinc in presence of different doses of cowdung. *Bangladesh J. Agril. Res.* **2011**, *36*, 151–163. [\[CrossRef\]](#)
77. Mishra, L.N.; Singh, S.K.; Sharma, H.C.; Goswami, A.M.; Bhana, P. Effect of micronutrients and rootstocks on fruit yield and quality of Kinnow under high density planting. *Ind. J. Hort.* **2003**, *60*, 131–134.
78. Singh, C.; Sharma, V.P.; Usha, K.; Sagar, V.R. Effect of macro and micronutrients on physico-chemical characters of grape cv. Perlette. *Ind. J. Hort.* **2002**, *59*, 258–260.
79. Narahari, S.; Rao, K.P.; Bahadur, V. Effect of Zinc (Zn) and Boron (B) on Growth, Yield and Quality of Cape Goose Berry (*Physalis peruviana* L.). *Int. J. Curr. Microbiol. App. Sci.* **2018**, *7*, 817–823. [\[CrossRef\]](#)
80. Kazemi, M. Effect of foliar application of iron and zinc on growth and productivity of cucumber. *Bull. Env. Pharmacol. Life Sci.* **2013**, *2*, 11–14.
81. Alharby, H.F.; Metwali, E.M.R.; Fuller, M.P.; Aldhebiani, A.Y. Impact of application of zinc oxide nanoparticles on callus induction, plant regeneration, element content and antioxidant enzyme activity in tomato (*Solanum lycopersicum* Mill.) under salt stress. *Arch. Biol. Sci.* **2016**, *68*, 723–735. [\[CrossRef\]](#)
82. Gutierrez-Miceli, F.A.; Oliva-Llavan, M.A.; Lujan-Hidalgo, M.C.; Velazquez-Gamboa, M.C.; Gonzalez-Mendoza, D.G.; Sanchez-Roque, Y. Zinc Oxide Phytonanoparticles' Effects of Yield and Mineral Contents in Fruits of Tomato (*Solanum lycopersicum* L. cv. Cherry) under Field Conditions. *Sci. World J.* **2021**, *2021*. [\[CrossRef\]](#)
83. Faizan, M.; Faraz, A.; Yusuf, M.; Khan, S.T.; Hayat, S. Zinc oxide nanoparticle-mediated changes in photosynthetic efficiency and antioxidant system of tomato plants. *Photosynthetica* **2018**, *56*, 678–686. [\[CrossRef\]](#)
84. Tarafdar, J.C.; Raliya, R.; Mahawar, H.; Rathore, I. Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). *Agric. Res.* **2014**, *3*, 257–262. [\[CrossRef\]](#)
85. Rizwan, M.; Ali, S.; Ali, B.; Adrees, M.; Arshad, M.; Hussain, A.; Rehman, M.Z.U.; Waris, A.A. Zinc and iron oxide nanoparticles improved the plant growth and reduced the oxidative stress and cadmium concentration in wheat. *Chemosphere* **2019**, *214*, 269–277. [\[CrossRef\]](#) [\[PubMed\]](#)
86. Tondey, M.; Kalia, A.; Singh, A.; Dheri, G.S.; Taggar, M.S.; Nepovimova, E.; Krejcar, O.; Kuca, K. Seed Priming and Coating by Nano-scale Zinc Oxide Particles Improved Vegetative Growth, Yield and Quality of Fodder Maize (*Zea mays*). *Agronomy* **2021**, *11*, 729. [\[CrossRef\]](#)