Int J Adv Life Sci Res. Volume 8(3) 121-127
https://doi.org/10.31632/ijalsr.2025.v08i03.011

International Journal of Advancement in Life Sciences Research
Online ISSN: 2581-4877
Journal homepage http://ijalsr.org

Original Article

Impact of Si-NPs on Eggplant Growth and Yield During Drought Stress

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Abstract

Silicon has also been noted as beneficial to plant growth, though its potential compared to ordinary silicon is not well established. Various physiological properties of nano-silicon allow it to be easily absorbed by plants, thereby influencing metabolic activities. Additionally, due to its non-structural porosity, it is also an effective transporter for agricultural chemicals. A field trial was conducted in 2023 to ascertain the effect of nano-silicon foliar spray on eggplant growth. The trial followed a completely randomised block design with three replications and nine treatments, including a control and four nano-silicon treatments. Data recorded included observations on plant growth, chlorophyll content, fruit yield, and mineral composition in fruits. The acquired data were analysed using the General Linear Model technique, and the means were compared using Duncan's multiple range test at a 5% probability. The results showed that the parameters of leaf size, as well as the number of leaves and leaf area, were enhanced by nano-silicon at 15 ml/L and 20 ml/L. These treatments resulted in an increase in chlorophyll content and total soluble sugars, as well as improved levels of chlorine, iron, protein, and nitrogen. Additionally, they influenced the levels of phosphorus, sodium, calcium, and iron, as well as chlorophyll and leaf area. The ratio of microelemental quantities in plant tissues relative to their equivalent amounts of sodium, magnesium, calcium, and potassium explains why protein levels are elevated.

Keywords: *Physiological Properties; Promote Eggplant Growth*; *Silicon Nanoparticles*

Introduction

It affects about 7 million people globally across diverse sectors, as prolonged dry spells reduce agricultural and livestock production. The majority of animals and ecosystems depend on water for life. The fact that protons are produced during water oxidation and then consumed by secondary photosystems to reduce NADP underscores the obvious importance of water to photosynthesis and metabolism as a medium and pathway for biological activity. In addition to silicon, another mineral nutrition-related application has been described in the literature to reduce drought tolerance (Sharma, Verma & Sharma, 2022; Rea *et al*., 2022; Mouhamad & Ahmad, 2024). Different crops exhibit varying drought tolerance. De Freitas *et al*., (2022) discovered that soybean, for example, showed greater drought tolerance under water deprivation. These findings were later confirmed by the same researchers in studies of many other crops. Borrell *et al*., (2024) found that osmotic control helps sorghum and legumes survive in water-scarce conditions. Potassium, on the other hand, improves the osmotic adjustment of plants such as maize. Damalas and Koutroubas (2024); and Xu *et al*., (2021) discovered that it relied on the crop parameter tested on hibiscus.

Yang *et al*. (2021) corroborated this finding in their investigation. Drought increases the activity of antioxidant enzymes in grasses. Silicon enhances the integrity of cell membranes against oxidative

Received on :19th February 2025; Revised version received on :15th June 2025; Accepted: 29th June 2025

stress by upregulating the lipid content of the membrane, preserving a variety of activities crucial for drought tolerance. The role or adjustment of silicon in the overall osmotic stress of dried plant cells is critical. This is something we typically take for granted and only appreciate when the tangible benefits are realised at a certain degree of stress. Salinity is generally added to drought because, in most field conditions, the quantity of salt increases due to a lack of water at the root zone. Evaporative demand rises as water is supplied, due to increasing evaporation availability across transpiring surfaces. It may also result in increased evaporative cooling—all of which would surpass control over maize plant transpiration and conveyance via osmotic channels across the cuticle. In fact, it has been reported that the loss of water via the leaves was reduced since these leaves had more water storage. Abdo *et al*., (2024) discovered that the application of silicon caused an increase in leaf water percentage. This does not yet imply the existence of specific mechanisms that direct each plant's response to drought, as long as the end result is achieved (Ali & Bijay, 2025).

The study aimed to determine the reaction of eggplant to silicon fertilizer at various levels, as well as the administration of formulated nitrogen and phosphorus treatments in terms of vegetative growth and eggplant production under field circumstances as an effective drought management technique.

Material and Methods

The study was conducted at Al-Madayn, Baghdad, Iraq, during the spring of 2022-2023. It was aimed to evaluate the response of eggplant (Solanum melongena L.) plants to foliar application of silicon nanoparticles regarding some growth, yield parameters, and activity of antioxidant enzymes under different levels of water deficit.

Plant Materials and Experimental Apparatus

After transplanting, under warmer conditions at temperatures above 70°F, eggplant seedlings develop 4–6 true leaves. Hardening off referred to the practice of conditioning the seedlings to outdoor conditions and involved a gradual increase in their exposure over a period of 1–2 weeks prior to transplanting. The experiment was conducted in an open field with proper weed control and irrigation scheduling. The area was divided into 9 plots of size 3 m × 3 m, with a 1 m separating distance between the plots. One of the plots was assigned as a control (only water treatment), while the rest were subjected to different Nano-Si foliar treatments at 10, 15, and 20 mg/L.

Soil and Fertilizer Application

All nutrient levels required by the soil test, plus the total requirements of the plant, were applied as a pre-planting fertiliser. Eggplant seeds were germinated about 8–10 weeks before the final frost date in the spring. When the soil temperature reached ≥16°C, they were transplanted into the field. Foliar irrigation was carried out at intervals of 5–7 days and depended on both the quantity of soil water and the evapotranspiration of plants.

Experimental Design and Treatments

The experiment was conducted using three replications in a Randomised Complete Block Design (RCBD). The treatments included the control and three levels of Si NPs (10, 15, and 20 mg/L). Foliar sprays were done twice during the cropping season, the first at 45-55 days after planting and the second at 80-90 days after planting.

Growth and Yield Attributing Parameters

At 75 days after planting by which time the plants had matured, 5 plants were randomly selected from each treatment to undertake various growth parameters, which included determination of plant height, fresh leaf weight, dry leaf weight, fresh root weight, and dry root weight. Leaf chlorophyll content was determined using a SPAD-502 meter (Minolta Camera Co. Ltd., Osaka, Japan). The fruits were harvested twice every week to record yield.

Antioxidative Enzyme Activity Measurement

The eggplant samples were collected, thoroughly washed, oven-dried at 70 °C, milled finely after drying, and well wet-boiled. SOD, CAT, and POD activities were assayed following the procedures of Jackson (1958), Watanabe and Olsen, (1965); Brown and Lilleland (1946). These assays are reflective of the activity of this set of enzymes and are very important in drought conditions for the detoxification of oxidative stress.

Statistical Analysis

The experiment was laid out in a randomized complete block design, and the data recorded were subjected to analysis of variance (ANOVA). Separation of treatment means was achieved by using Waller Duncan k-ratio *t*-test approximation at 0.05 levels of significance. The experiments were, however, repeated thrice with three replicates each to ensure statistical accuracy and conclusiveness of the results.

Result

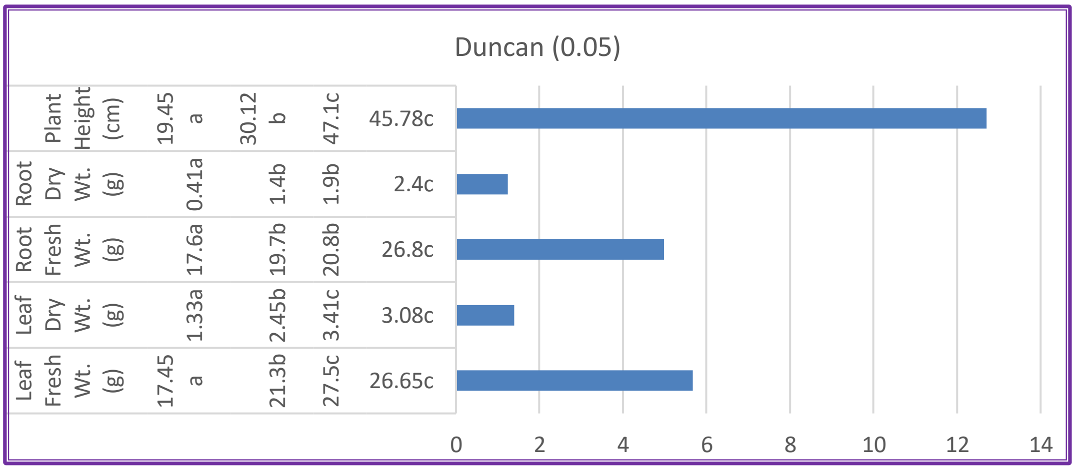

Figure 1: Effects of Nano silica on Eggplant Growth Parameters; Means with Different Letters Following Them Differ Significantly at P < 0.05 (Duncan Test).

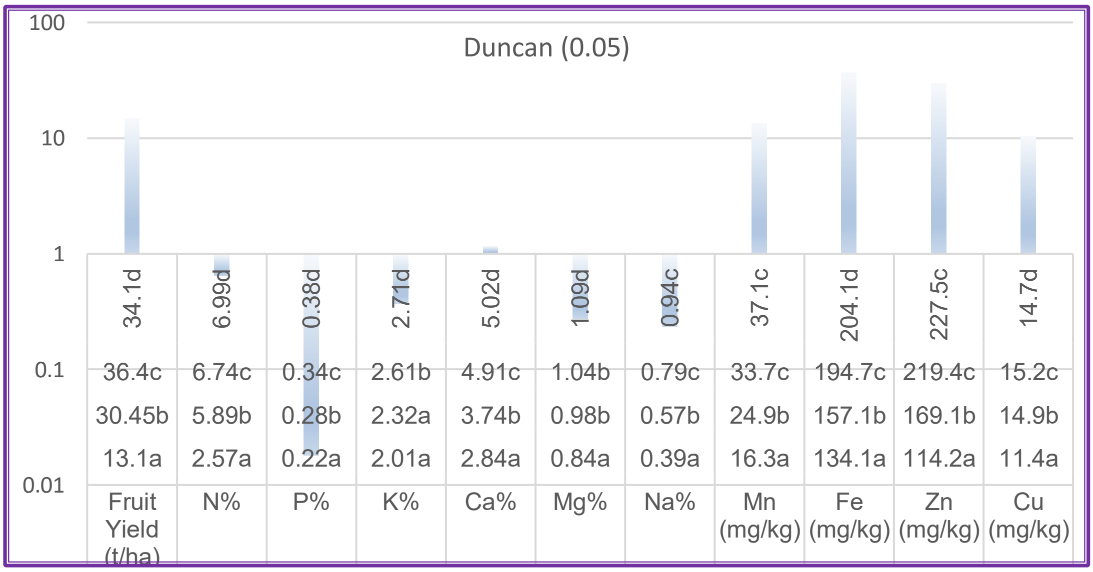

Figure 2: *Effects of Nano silica on Eggplant Yield and Macro and Micro-Nutrient Parameters; Means with Different Letters are Significantly Different at P < 0.05 (Duncan Test).*

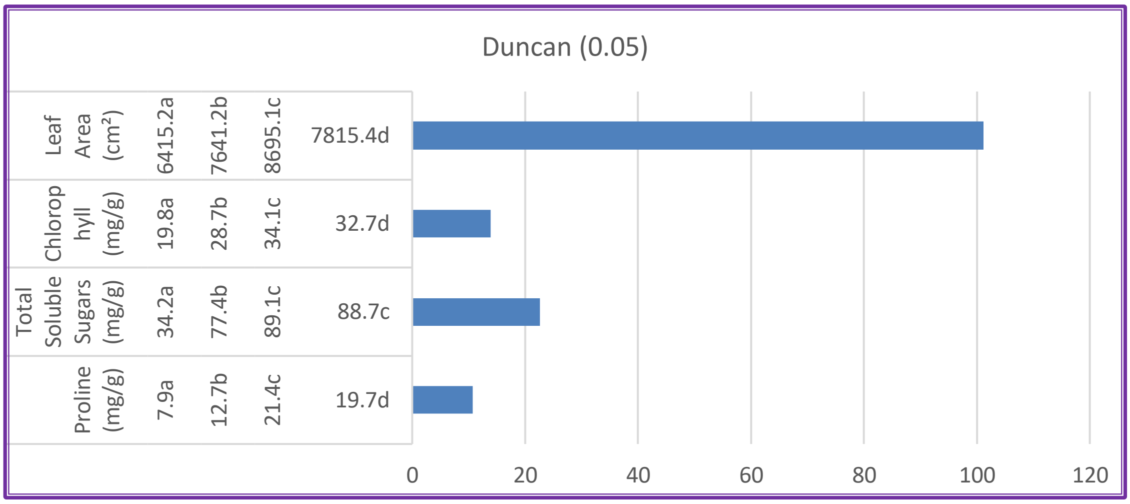

Figure 3: Effects of Nano silica on Proline, Total Soluble Sugars, Chlorophyll Content, and Leaf Area; Means with Different Letters Are Significantly Different at $P < 0.05$ (Duncan Test)

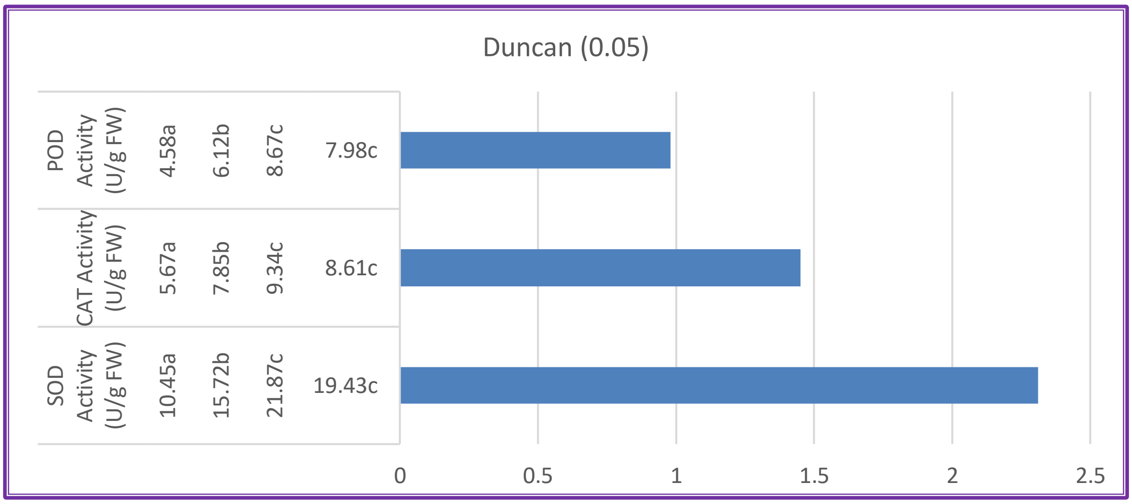

***Figure 4**: Effect Of Nano silica on Antioxidant Enzyme Activities in Eggplants Under Drought Stress*

Discussion

The nanosilica material can be produced through mesoporous silicon nanomaterials; therefore, it has very good potential to be a nanocarrier for agricultural treatments. By this formulation, therefore, some change in the metabolic processes of the plant can be realized that enhances general resistance of the plant to environmental stress; therefore, it enhances growth and photosynthesis efficiency of seedlings by affecting root development.

The current study reveals, as illustrated in Figure 1, that nanosilica enhanced the plant's mechanism toward salt stress as well as several related parameters characteristic of plant and root growth, nutrient use efficiency, chlorophyll content, proline level, and soluble sugar. In particular, 15 mg/L and 20 mg/L nanosilica recorded significantly increased fresh weight compared to all other treatments, with the 20 mg/L treatment being optimal for root growth. These findings are in agreement with results found by other authors, such as Amin and Juita (2023), De Souza Júnior *et al*. (2022), and Roy *et al*. (2025), indicating that nanosilica improves salt tolerance mechanisms in plants. The fresh and dry weights of leaves and roots increased with increasing nanosilica application up to 15 mg/L and 20 mg/L. Specifically, root growth was highest for the 20 mg/L treatment, significantly different from both 10 mg/L and 15 mg/L, as well as the control. These results coincide, by all means, with those who earlier reported that nanosilica positively influenced both biomass and plant growth. Disagreement with the findings is simultaneously expressed by another set of researchers, who suggest that higher nanosilica concentrations do not make a difference regarding biomass. The variation observed could be due to the disparity in the type of plant species that responded to different environmental factors in a different manner.

The maximum fruit yield was recorded at 15 mg/L and 20 mg/L nanosilica, which was significantly different from 10 mg/L and the control. As Figure 2 illustrates, the impact of nanosilica application on the levels of macro- and micronutrients in eggplant fruits is evident. For instance, nitrogen, phosphorus, potassium, calcium, magnesium, sodium, manganese, iron, zinc, and copper content were found to be higher in the fruit tissues obtained from plants treated with 15 mg/L and 20 mg/L nanosilica. This finding was asserted by Alharbi *et al*. (2024) in the increased nutrient uptake by nanosilica-modified plants.

As shown in Figure 3, nanosilica applied through the leaves caused a marked increase in leaf area, chlorophyll content, total soluble sugars, and proline concentration, with more pronounced effects at 15 mg/L and 20 mg/L. An increase in these parameters indicates an enhanced ability for osmotic regulation, leading to much better tolerance of drought stress. This finding is similar to results reported by Kaur *et al*. (2023), Ismail *et al*. (2022), and Alazzawi, Al-Delfi and Mouhamad (2024), who observed nanosilica-induced improvements in certain traits. However, such claims were recently contradicted by Gohar *et al*. (2024) and Zaman, Ayaz and Park (2025), who found no effect on most cultivars regarding variations in chlorophyll content, suggesting a clear species-specific response to nanosilica.

The actions of antioxidant enzymes, namely SOD, CAT, and POD, were significantly enhanced in eggplant fruits due to nanosilica treatments, as illustrated in Figure 4. More specifically, a dose-dependent response was observed with the 15 mg/L and 20 mg/L treatments. These enzymes directly scavenge ROS, providing an additional line of defence for the plant against oxidative stress. For example, there was a 109% increase in SOD activity in plants treated with 15 mg/L nanosilica, indicating that these plants possess a better mechanism for detoxifying oxidative radicals. This finding is in agreement with the results of studies conducted by Gulzar *et al*. (2021), Mahdi, Mutlag and Mouhamad (2019), and Atiyah *et al*. (2023), which indicated that an increase in SOD activity may reduce the extent of ROS damage in response to drought stress.

These results provide strong evidence that nanosilica improves both growth and physiological performance in eggplants under salt stress conditions, supporting its potential use as a soil amendment or foliar treatment for improving plant productivity under stress.

Limitations and Future Scope

While this study shows that silicon nanoparticles can improve eggplant growth and yield under drought, it was limited to a single location and specific application methods, which may affect how widely the results apply. Long-term effects on soil health and food safety were not explored. Future studies must adopt a variety of approaches, tools, and dosages to investigate the underlying biological mechanisms, in varied environments, and also assess potential environmental impacts to enhance the safe and sustainable use of these nanoparticles in agriculture.

Conclusion

The current study demonstrates that nanosilica application can significantly enhance the growth, yield, and stress tolerance of eggplant under salt-stress conditions. Treatments with nanosilica at 15 mg/L and 20 mg/L were found to be optimal for improving growth parameters, nutrient uptake, and biochemical markers associated with stress. These findings suggest that nanosilica could be an effective strategy for enhancing agricultural productivity in salt-stressed environments. However, further research is needed to fully understand the mechanisms behind these effects and to explore the long-term impact of nanosilica on soil health and plant growth.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgement

The study's authors would like to extend their profoundest gratitude to all participants for their significant contributions.

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