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Research Article

Silicon increased the growth, productivity, and nutraceutical quality of tomato (*Solanum lycopersicum* L.)

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Abstract

Tomato (*Solanum lycopersicum* L.) is considered one of the most important horticultural crops worldwide due to its nutritional and organoleptic properties. Instead of chemical fertilizers, recent research has shown in several plant species the importance of silicon fertilization. Hence, the present investigation aims to evaluate the effect of three different doses (low, medium, and high dose) of silicon on the growth (stem length and diameter, root length diameter, and stem, leaf and root biomass), productivity (polar and equatorial fruit diameter, number of fruits per bunch and plant, and yield), and nutraceutical quality (total soluble solids, titratable acids, and vitamin C) parameters of tomato. The Si treatment affected the evaluated parameters in a dose dependent way in almost all the parameters evaluated. Despite the tomato is classified as a non-Si accumulator, it has a significant response to Si treatment at a low dose of 0.15 g plant^{-1}, medium dose of 0.25 g plant^{-1}, and high dose of 0.35 g plant^{-1} after 120 d of transplantation in terms of plant growth, yield, and quality parameters. The effectiveness of Si nutrition is dependent on factors such as element source, plant species, and cultivar, and even, the absorption and bioaccumulation capacity of this element could be different between varieties.

Keywords: non-accumulator plants; sustainability; Solanaceae family; soil fertilization; plant biostimulant

Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the Solanaceae family, which includes petunia (*Petunia* sp.), pepper (*Capsicum annuum* L.), potato (*Solanum tuberosum*), and tobacco (*Nicotiana tabacum* L.). It is considered one of the most important horticultural crops worldwide due to its nutritional and organoleptic properties (Meng *et al.*, 2022), with 37.3 million tons produced in 2022 (FAO, 2022). Due to its consumption

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as a fresh vegetable, cooked food, or as a processed industrial product, tomato is one of the main sources of carotenoids, and other vitamins and minerals in human daily intake (Ali *et al.*, 2020). In comparison with *Arabidopsis thaliana* and *Oryza sativa*, *S. lycopersicum* has unique characteristics as a model study plant such as fruit production, compound leaves, sympodial shoots, and mostly indeterminate growth habits (Marmiroli *et al.*, 2022). Consequently, there is a need for enhancing the global production and productivity of horticultural crops to assure food safety according to the increasing world population (Stella *et al.*, 2019).

Nutrition is the second factor that most influence tomato management, after water availability (Ulla *et al.*, 2021). Consequently, chemical fertilizers are used for conventional fertilization, since the importance of the macro-elements nitrogen, phosphorous, potassium and some microelements such as sulfur, magnesium, and calcium is recognized (Hasnain *et al.*, 2020). However, recent research has also shown in several plant species the importance of silicon fertilization via foliar or soil application through different sources (i.e. calcium and potassium silicate, and silicic acid) for higher agricultural production, lower incidence of pests and diseases, as well as increasing the nutritional quality of fruits (Al-Murad *et al.*, 2020). Moreover, Si application has a positive effect on biotic and abiotic resistance, photosynthetic processes, nutrition, yield, and quality in many crops like barley (Wade *et al.*, 2022), finger miller (Mundada *et al.*, 2021), onion (Venancio *et al.*, 2022), rice (Huang *et al.*, 2021), soybean (Hussain *et al.*, 2021), among others.

Silicon (Si) as silicon dioxide (SiO_2) is the second most abundant element on the earth´s surface after Oxygen (O_2) in amounts of 50-400 g Si Kg^{-1} (Sommer *et al.*, 2006; Kurdali *et al.*, 2019). Although its abundance in soil, factors such as cations, organic compounds, pH, temperature, and water content influence the Si availability to plants in the form of silicic acid (H_4SiO_4) or mono silicic acid [$Si(OH)_4$] (Chen *et al.*, 2018). These plant forms are usually available at pH <9 and concentrations between 0.1 and 2.0 mM which is a concentration comparable to other major plant nutrients such as calcium and potassium (Knight and Kinrade, 2001). The variation of Si concentration in leaves and shoots is due to the Si uptake and passage mechanism in different plants (Bhardwaj and Kapoor, 2021). Based on water uptake capacity, the Si adsorption of higher plants is classified as active uptake (Si uptake > water uptake), passive uptake (Si uptake = water uptake), and rejective uptake (Si uptake < water uptake) (Kaur and Greger, 2019). Moreover, based on the Si accumulation in tissues, higher plants are classified as accumulators (>4% Si; rice), intermediate (2-4%; soybean), and non-accumulators (<2% Si; tomato) (Marmiroli *et al.*, 2022).

Despite classification into rejective uptake and non-accumulator categories of Si, the tomato has demonstrated amelioration of biotic and abiotic stressors such as high pH (Khan *et al.*, 2019), water deficit (Zhang *et al.*, 2018), pathogen attack (Jiang *et al.*, 2019), and Salinity (Li *et al.*, 2015) after Si treatment. The beneficial effect of Si was also studied at postharvest shelf-life and quality parameters of tomato fruit (Costan *et al.*, 2020). Many research has been developed on the effect of Si to ameliorating biotic and abiotic stress in tomatoes, but there is scarce information on the effect of Si on plants that were not under any kind of plant stressor. Hence, the present investigation aims to evaluate the effect of three different doses of Si (low, medium, and high dose) on the growth, productivity, and nutraceutical quality parameters of tomato.

Materials and Methods

Site description

The development of the research was carried out in the greenhouse of the Experimental Campus "La María" located at km 7.5 of the Quevedo-Mocache road in the Mocache canton, Los Ríos province. The geographical location is 1°04'48.6" South latitude and 79°30'04.2"West longitude, at an altitude of 75 m above sea level. The greenhouse is located in a humid tropical climate zone, with an average annual temperature of

25.4 °C, average annual rainfall of 3029.30 mm; 88.0% RH, and 894.0 light hours per year^{-1}. The soil presents a flat topography, and loamy-silty texture with an average pH of 5.5.

Seed germination and plant growth conditions

Certified tomato seeds of the 'Acerado 3059' cultivar of determined growth were used. The tomato seeds were disinfected in 5.0% sodium hypochlorite for 10 min, resting for 3 to 4 h before sowing in the seedbed. The seeds were sown in polyethylene trays with 200 cavities, which contained the commercial substrate Sogemix® (moisture content 38.5%, pH 4.5–5.5, electrical conductivity 2.0 dS m^{-1}, bulk density 0.7–1.0 mg m^{-3}, grain size 125–250 μm, with 91.1% organic matter: N, 800–2500 mg kg^{-1}; P, 150–850 mg kg^{-1}; Na, 340 mg kg^{-1}; NaCl, 850 mg kg^{-1}). The seeds were planted at the rate of one seed per cavity at a depth corresponding to two volumes of the seed. The irrigation applied to the trays was carried out daily for a homogeneous emergence of the seedlings. The transplant was carried out under shady conditions, when the seedlings had a height between 10 to 15 cm, in 1 kg bags. The substrate used consisted of a mixture of sand plus the commercial substrate with a ratio of 1:1. Two plants were placed in each bag to ensure the success of the transplant, and then one was removed, leaving the ones with the best characteristics and with the most homogeneity among the entire population. Once the transplant was done, the daily application of irrigation began, with the use of distilled water. All the tasks recommended in the tomato crop were carried out, except for Si treatments at the time of transplantation. Daily irrigations were carried out up to field capacity, thus avoiding water stress in the plants. The application of water was made by moistening the substrate in its entirety.

Experimental design

A completely randomized design of four treatments with four repetitions was used. Each experimental unit consisted of 10 plants, for a total of 40 plants per treatment (Table 1).

Table 1. Si dose treatments applied in research

Treatments		Description*
Code	Si dose (g. plant^{-1})	
T1	0	Distilled water application. Control
T2	0.15	Si low dose application
T3	0.25	Medium dose application of Si
T4	0.35	High dose application of Si

*Dose classification was done according to Marmiroli *et al.* (2022).

Plant growth parameters

In plant growth parameters, stem length (cm) and stem diameter (cm) parameters were evaluated after 30, 45, and 60 d after transplantation. And root length (cm) and root biomass (g) were evaluated after 120 d after transplantation. After stem, root, and leaves fresh biomass were registered, the samples were placed in paper bags and placed in a drying oven (FED 115 brand; Binder, Germany) at 65.0 °C for 72 h until constant mass. Finally, they were weighed on an analytical balance (stem, leaves, and root dry biomass).

Productivity parameters

The evaluation of the fruits was carried out in the first harvest, in the state of physiological maturity. They were evaluated at 120 d after transplantation. Polar and equatorial diameter of the fruits (cm). were determined for each treatment. 40 fruits were selected and measured with a caliper. The number of fruits per plant was carried out by counting when 50.0% of the fruits set fruit on each plant individually for each treatment, and the average value was used. For fresh biomass of each treatment, 40 fruits were weighed on an analytical balance. For agricultural yield (kg. plant^{-1}), the total production in each harvested treatment was determined by the direct weight of the fruits in each plot.

Nutraceutical quality parameters

To determine the nutraceutical quality indicators, samples of 10 fruits per treatment were taken and sent to the laboratory where the variables of fruit acidity percentages, total soluble solids, and Vitamin C content were determined. They were evaluated after 120 d of transplantation. Fruits were picked from the second and third raceme, with intense red colour, were used. Seeds were removed, and the pulp was kept in a freezer (-20 °C), in the dark, protected with aluminium foil until the analysis was carried out. For determining chemical characteristics (titratable acidity, soluble solids, and vitamin C), fruit pulp samples were crushed and homogenized using a food processor at low speed (3,000 rpm) for two minutes for each sample. Titratable acidity was determined by titration method, using 10 g of tomato pulp, 100 mL of distilled water and two drops of phenolphthalein. This solution was titrated with a 0.1 mol L^{-1} NaOH standard solution. Values were expressed in citric acid percentage (g of citric acid/100 g fresh tissue) (Watanabe *et al*., 2015). Soluble solids were determined by direct reading in a bench-top refractometer (Optech model RMT), at room temperature (±18 °C), with values expressed in Brix (°Brix). Vitamin C was determined by the titration method described by Sha *et al.* (2015), for this, 20 g of a solution composed of 25 g tomato pulp and 50 g of 2% oxalic acid were transferred to a 50 mL volumetric balloon and its volume was completed with oxalic acid. The solution was filtered in filter paper and a 10 mL aliquot was titrated with DCPIP (2,6-dichlorophenol indophenol). Results were expressed in mg vitamin C for 100 g of sample.

Statistical analysis

Statistical analysis was performed with SPSS v22.0 (SPSS Inc., Chicago, Ill.) program. Data were evaluated for normality by Shapiro-Wilk modified test before being subjected to analysis of variance (ANOVA). The significance of the differences between mean values was tested with Duncan's Multiple Range tests (DMRT) at P≤0.05, following one-way ANOVA. Percentage values were subjected to a logarithmic transformation before analysis. Results were expressed as mean values ± SE.

Results

Plant growth parameters

For stem length at 30, 45, and 60 days after transplanting (Figures 1a, 1b, and 1c) significant differences were found between treatments. At 30 d after the transplant, the greatest length of the stem was reached in the treatments where Si concentrations of 0.15 g $plant^{-1}$, 0.25 g $plant^{-1}$, and 0.35 g $plant^{-1}$ were applied. respectively, without significant differences between them, which significantly exceeded the control treatment in which Si was not applied. Similar results were achieved at 45 and 60 d after transplanting, which indicates a significant increase in the effect of Si on the length growth of tomato plants.

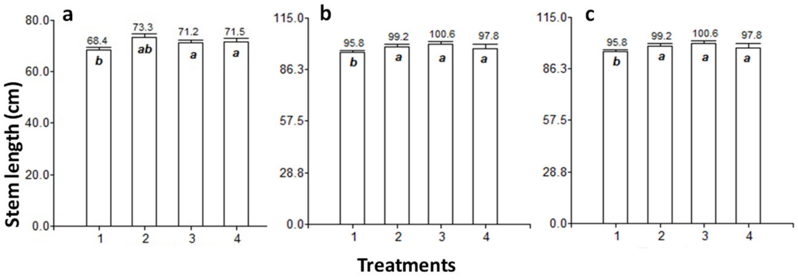

Figure 1. Average values of stem length (cm) for the different treatments
T1 (control treatment), T2 (treatment 0.15 g. $plant^{-1}$ of Si), T3 (treatment 0.25 g. $plant^{-1}$ of Si), and T4 (treatment 0.35 g. $plant^{-1}$ of Si) at 30 d after transplantation (a), at 45 d after transplantation (b), and at 60 d after transplantation (c). Different letters indicate significant differences for $p < 0.05$.

No significant differences were found between the treatments for stem diameter 30 d after transplanting (Figure 2a). However, at 45 and 60 d after the transplant (figures 2b and 2c) the effect of the Si applications caused significant differences in the diameter of the stems, although without a marked difference between the four treatments. The diameter of the stems of the treatments with Si at 0.25 and 0.35 g plant^{-1} was similar, even without a marked difference for the treatment where Si was not applied (control treatment). It is highlighted that at 45 and 60 d after the transplant, there is no effect of Si applications at 0.15 g plant^{-1} on the diameter of the stems of tomato plants.

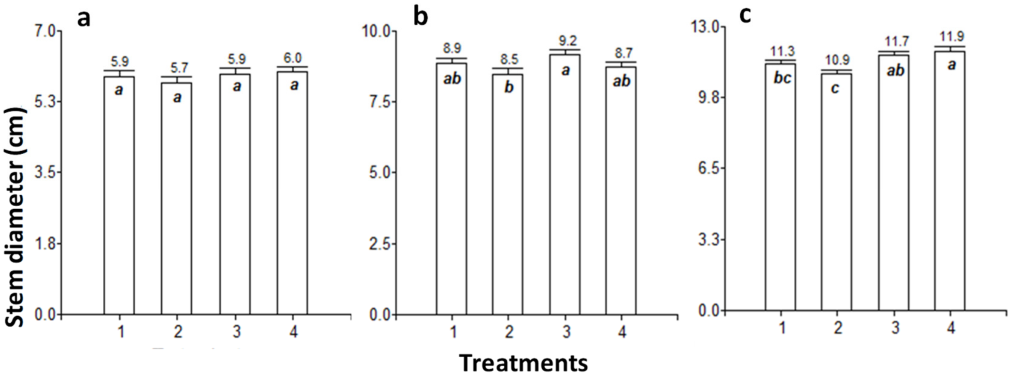

Figure 2. Average values of stem diameter (cm) for the different treatments
T1 (control treatment), T2 (treatment 0.15 g. plant-1 of Si), T3 (treatment 0.25 g. plant-1 of Si), and T4 (treatment 0.35 g. plant-1 of Si) at 30 days after transplantation (a), at 45 days after transplantation (b) and at 60 days after transplantation (c). Different letters indicate significant differences for $p < 0.05$.

Regarding fresh leaf biomass after 120 d of transplantation (Figure 3a), the different treatments showed significant differences. The highest values of fresh leaf biomass were reached in the treatments in which Si was applied at 0.15; 0.25 and 0.35 g plant^{-1}, without significant differences between them, with leaf biomass values of 92.6; 77.1, and 75.7 respectively, in turn, the treatments with 0.25 and 0.35 g plant^{-1} did not present significant differences with the control treatment. In the case of dry leaf biomass after 120 d of transplantation (Figure 3b), no significant differences were found between the four treatments studied.

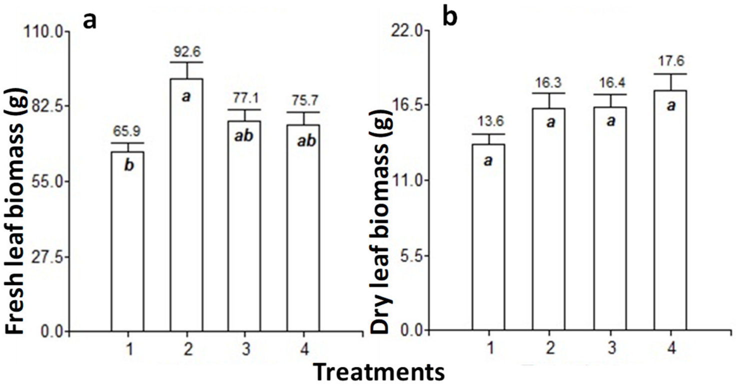

Figure 3. Average values leaf biomass (g) at 120 days of transplantation
fresh leaf biomass (a) and dry leaf biomass (b) for the different treatmentsT1 (control treatment), T2 (treatment 0.15 g. plant-1 of Si), T3 (treatment 0.25 g. plant-1 of Si), and T4 (treatment 0.35 g. plant^{-1} of Si). Different letters indicate significant differences for $p < 0.05$.

For fresh and dry biomass of the stem after 120 days of transplantation (Figures 4a and 4b), the treatments showed significant differences in both variables. The highest levels of biomass corresponded to the treatments with 0.25 g plant^{-1} and 0.35 g plant^{-1} of Si, without significant differences between them, followed by the treatment in which Si was applied at 0.15 g plant^{-1}, while the lowest values of fresh and dry stem biomass corresponded to the control treatment.

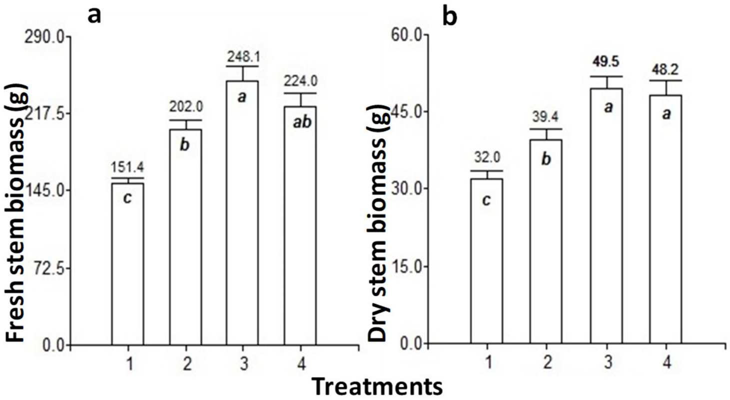

Figure 4. Average values of stem biomass (g) at 120 days of transplantation
Fres stem biomass (a) and dry stem biomass (b) for the different treatments T1 (control treatment), T2 (treatment 0.15 g. plant^{-1} of Si), T3 (treatment 0.25 g. plant^{-1} of Si), and T4 (treatment 0.35 g. plant^{-1} of S). Different letters indicate significant differences for $p < 0.05$.

For the length of the root after 120 days of transplantation (Figure 5a), the applications of Si had significant differences between the treatments. The roots with greater lengths were reached in the treatments when Si was applied at 0.25 g plant^{-1} and 0.35 g plant^{-1} with root lengths close to 50 cm, which significantly exceeded the control treatment and even the 0.15 g plant^{-1} of Si treatment. The latter mentioned treatments without significant differences between them, whose root lengths reached values around 35 cm.

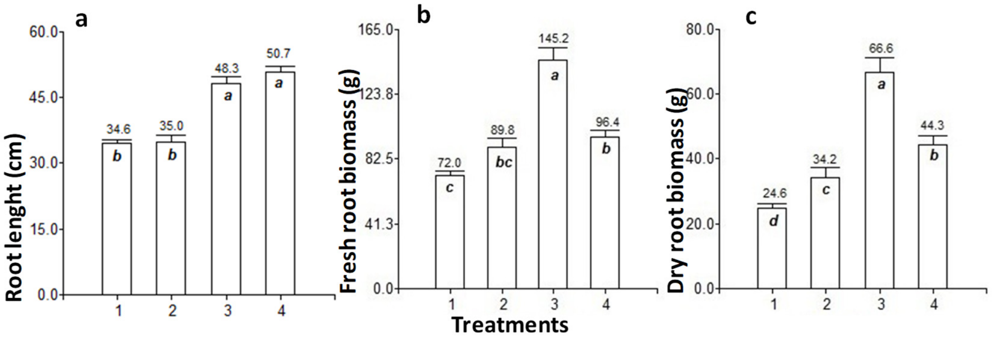

Figure 5. Average values of root length (cm) and root biomass (g) at 120 days of transplantation
Root length (a), fresh root biomass (g), and dry root biomass for the different treatments. T1 (control treatment), T2 (treatment 0.15 g. plant^{-1} of Si), T3 (treatment 0.25 g. plant^{-1} of Si), and T4 (treatment 0.35 g. plant^{-1} of Si). Different letters indicate significant differences for $p < 0.05$.

Significant differences were found between the treatments for the variables of fresh root biomass and dry root biomass (Figures 5b and 5c). In the fresh root biomass (Figure 5b) the application of Si at 0.25 g. plant^{-1} significantly outperformed the rest of the treatments, with values above 140 g, followed by the treatments with 0.15 g. plant^{-1} and 0.35 g. plant^{-1} without significant differences between the latter two and fresh biomass values close to 90 g. The control treatment only reached values of fresh root biomass of 72.0 g. A similar response was produced for the dry root biomass (Figure 5c) in which the treatment with S at 0.25 g plant^{-1} significantly exceeded the rest of the treatments with values above 60.0 g, followed by the treatment with Si at 0.35 g plant^{-1}, followed by the treatment with 0.15 g plant^{-1}, while the lowest dry biomass of the roots corresponded to the control treatment.

Productivity parameters

Both for the number of fruits per bunch (Figure 6a) and for the number of fruits per plant (Figure 6b), there were significant differences between the treatments. The highest number of fruits per bunch and number of fruits per plant corresponded to the treatment with Siapplied at 0.35 g plant^{-1}, followed by the Si treatments at 0.25 g plant^{-1} and 0.15 g plant^{-1}. The lowest values corresponded to the control treatment. The same pattern of response with significant differences between the treatments and the same order of merit of the treatments was reached for the polar and equatorial diameter of the fruit and agricultural yield (Figure 7).

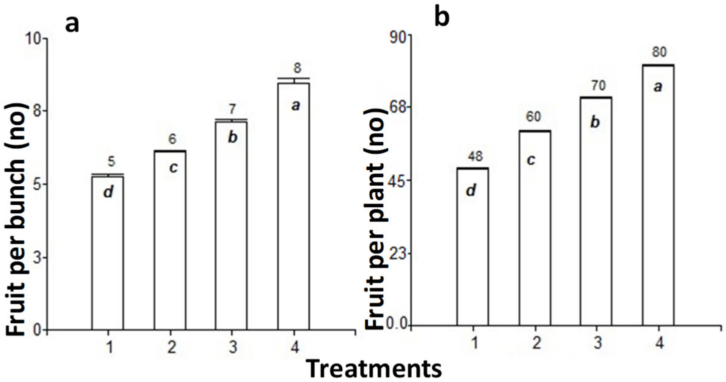

Figure 6. Average values of the number of fruits at 120 days after transplantation

Fruits per bunch (a) and fruits per plant (b) for the different treatments. T1 (control treatment), T2 (treatment 0.15 g. plant^{-1} of Si), T3 (treatment 0.25 g. plant^{-1} of Si), and T4 (treatment 0.35 g. plant^{-1} of Si). Different letters indicate significant differences for $p < 0.05$.

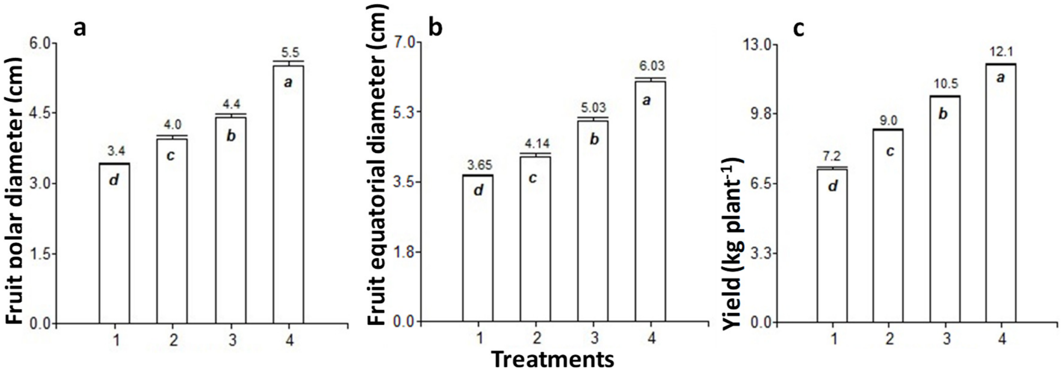

Figure 7. Average values of the diameter of the fruit and agricultural yield at 120 days after transplantation

Polar diameter of the fruit (a), and the equatorial diameter of the fruit (b), agricultural yield (c) for the different treatments. T1 (control treatment), T2 (treatment 0.15 g. plant^{-1} of Si), T3 (treatment 0.25 g. plant^{-1} of Si), and T4 (treatment 0.35 g. plant^{-1} of Si). Different letters indicate significant differences for $p < 0.05$.

Quality parameters

For the titratable acidity of the fruit, significant differences were demonstrated between the treatments (Figure 8a). The highest levels of titratable acidity corresponded to the treatment in which Si was not applied to the plants, followed by the treatments with Si applied at 0.15 and 0.35 g. plant^{-1}, although without significant differences between these two treatments. The treatment with lower levels of acidity corresponded to the treatment with Si at 0.25 g. plant^{-1}. Contrarily, the highest percentage of total soluble solids and ascorbic acid (vitamin C) was achieved by Si treatment at 0.35 g. plant^{-1}, and as the amount of Si applied per plant decreased (0.25 g. plant^{-1} and 0.15 g. plant^{-1}), both parameters decreased in the tomato fruit (Figures 8b and 8c).

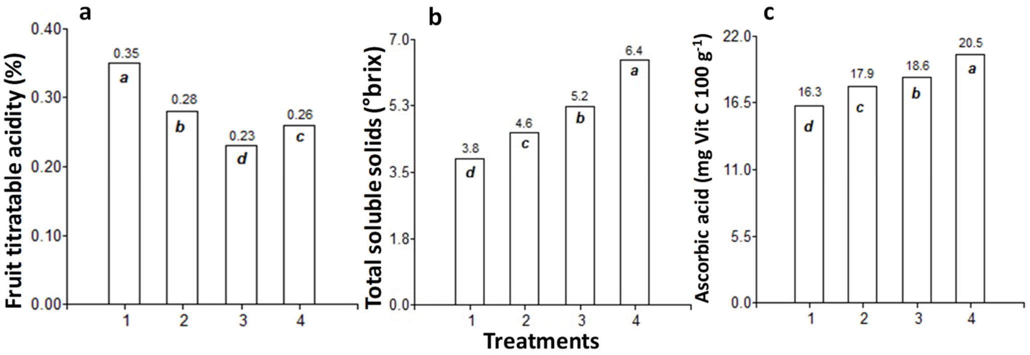

Figure 8. Average values of the Fruit titratable acidity (%), total soluble solids (°brix) and ascorbic acid (mg vit C 100 g^{-1}) at 120 days after transplantation

Fruit titratable acidity (a), total soluble solids (b), and ascorbic acid (c) for the different treatments. T1 (control treatment), T2 (treatment 0.15 g. plant^{-1} of Si), T3 (treatment 0.25 g. plant^{-1} of Si), and T4 (treatment 0.35 g. plant^{-1} of Si). Different letters indicate significant differences for $p < 0.05$.

Discussion

Si is translocated by Lsi1, Lsi2, Lsi3, and Lsi6 protein transporters and intrinsic proteins such as Nod26, principally in accumulator plants (Mandlik *et al.*, 2020). Although tomato has a rejective uptake and is a non-accumulator of Si (Kaur and Greger, 2019; Marmiroli *et al.*, 2022), a homolog of Lsi1 rice aquaporin was recently isolated and characterized in tomato (Sun, 2020). They concluded that low Si accumulation in tomato is due to the lack of a functional Si efflux transporter Lsi2, which is required for active Si uptake, although, SILsi1 is functional. The Si nutrition has a dual role in the soil-plant relationship, it increases the plant resistance against biotic and abiotic stressors, and it also enhances soil fertility by transforming soil nutrients to those available forms to plants, and by improving physicochemical characteristics of soil (Rajput *et al.*, 2021). Moreover, Si is usually classified as a non-essential element for plants, nonetheless, it could be re-classified as a quasi-essential element due to the fact that plant with Si-nutrient availability show better growth than no-nutrient availability ones (Ali *et al.*, 2020).

The absorption of suitable quantities of mineral nutrients by roots and plant leaves, and their organs transportation by the stem of the plant, are elemental for optimal development and plant growth (Schjoerring *et al.*, 2019). In our study, the growth and mass of tomato stem were significantly increased by Si treatments in comparison with the control treatment. According to Alsaeedi *et al.* (2019), the length and mass of stems and roots were evaluated, and they found a greater stimulation in these growth physiological parameters after the treatment of cucumber seeds with 200 mg L^{-1} of Si nanoparticles. Similar results were obtained in tomato (Khan *et al.*, 2020) and maize (Suriyaprabha *et al.*, 2012) seedlings after Si nanoparticles treatment. Si can affect positively nutrient stem translocation in plants by different methods such as organic acid formation by roots;

plant membranes networking; turning on H^+-ATPases in the membrane and boosting K absorption (Buchelt *et al.*, 2020).

For fresh leaf biomass, the obtained results showed that they were statistical differences between treatments in comparison with the control treatment. According to Hasanuzzaman *et al.* (2018), exogenous applications of Si in *Brassica napus* plants under high temperatures, improve the relative water content, the number of photosynthetic pigments and therefore the biomass and length of the plant leaf. The reduction of water loss by transpiration or through cuticles could be due to the deposition of Si crystals below the leaf on epidermal cells (Guerriero *et al.*, 2020). Specifically, in epidermal cell walls, Silica forms hydrated bonds with water by polar and polymerized silicic acid to maintain the water status of the plant from leaf structure (Souri *et al.*, 2021). The leaf proteome of *Capsicum annuum* was analysed after salinity stress and Si (K_2SiO_3) supplementation (Manivannan *et al.*, 2016). They found that 129 proteins were expressed differentially during salinity stress and/or Si treatments. Si treatment upregulated 67 protein spots (Luo *et al.*, 2002) such as Adenylosuccinate synthase which is related to purine metabolism leading to enhanced growth and biomass accumulation of leaf.

In biomass and length of tomato roots, our results showed statistical differences between Si treatments in comparison with the control treatment. In a study, the tomato roots were supplemented with Si (Na_2SiO_3) after salt-stressed treatment (Muneer and Jeong, 2015). They found that 40 proteins were downregulated in roots under salinity stress (25 and/or 50 mM NaCl/-Si), and the same 40 proteins (17% stress response related proteins, 11% plant hormones-related proteins; 11% cellular biosynthesis, and other transcriptional regulation, RNA binding, and secondary metabolism proteins) were upregulated with Si supplementation. Although, Si has a beneficial effect on roots and stomatal orifices, and thus it influences the absorption and consumption of water (Rastogi *et al.*, 2021).

Our results showed statistical differences between treatments in productivity parameters such as the number of fruits (per bunch and plant), fruit length (polar and equatorial), and yield in comparison with the control treatment. In contrast, the results obtained by Peñazola (2019) did not show statistical differences between treatments on the above-mentioned parameters after Si application on tomato fruits. As mentioned before, the effectiveness of Si nutrition is dependent on factors such as element source, plant species, and cultivar (Alam *et al.*, 2022). Even, the absorption and bioaccumulation capacity of this element could be different between varieties (Wangkaew *et al.*, 2019). Nonetheless, Jarosz (2014) obtained a significant increase in the total fruit yield of plants fertilized with the Si-enriched nutrient solution (15.98 kg plant^{-1}) compared to plants in control treatments. Moreover, Gomma *et al.* (2021) concluded that foliar treatment of Si (K2SiO3) at 1000 cm^3 L^{-1} after 40, 60, and 80 d of sowing, increased the growth, yield, and quality characters of *Zea mays* plants.

On quality parameters, the Si treatment showed less titratable acidity values and higher total soluble solids (°brix) compared with the control treatment. Photosynthesis is an elementary physiological mechanism that has a direct effect on plant biomass production and development processes (Muhammad *et al.*, 2021). Si increases the chloroplast structure and chlorophyll content and therefore it enhances the photosynthetic activity (Pavlovic *et al.*, 2021). Thus, the increased sugar production in leaves is translocated to the fruits by increasing their total soluble solids content and decreasing the titratable acidity with a low respiration rate (Valencia, 2002). Moreover, Si treatment showed the highest vit C content in a dose-dependent manner in comparison with treatment control. The Si treatment at 0.35 g showed the highest vitamin content C probably due to a lower metabolic activity. Nonetheless, the vitamin C content also could be dependent on the tomato cultivar, temperature, and maturity stages (Islam *et al.*, 2018).

To our knowledge, this is the second study about the effect of different Si doses from low (0.15 g. plant^{-1}) to high doses (0.35 g. plant^{-1}) under no type of stressors. The results of the first study concluded that the effect of Si on tomato plants is not only cultivar-dependent, but it is also unaffected by treatment intensity (Marmiroli *et al.,* 2022). Our results showed that high or low Si concentrations on plants have variable impacts on physiological, transcriptomic, and chemical levels depending on each cultivar, with just a few similarities. Treatment with Si may have a priming effect on the plant depending on its sensitivity to Si, However, the subject remains unclear in numerous areas and deserves additional examination.

Conclusions

Despite the tomato is classified as a non-Si accumulator, it has significant response to Si treatment at low dose of 0.15 g plant^{-1}, medium dose of 0.25 g plant^{-1}, and high dose of 0.35 g plant^{-1} after 120 d of transplantation in terms of plant growth, yield, and quality parameters. The effectiveness of Si nutrition is dependent on factors such as element source, plant species, and cultivar, and even, the absorption and bioaccumulation capacity of this element could be different between varieties. However, more research based on "omic" technologies needs to be developed to elucidate the mechanisms of Si action on plant model studies such as tomato.

Authors' Contributions

Conceptualization: J.J.R-P and L.T.LL-R; Data curation; H.C.T-T; Formal analysis; L.G.H-M and T.R-G; Funding acquisition; J.J.R-P; Investigation; H.C.T-T; Methodology; T.R-G; H.C.T-T and T.R-G; Supervision; J.J.R-P, L.T.LL-R and T.R-G; Validation; L.G.H-M; Visualization; L.T.LL-R; Writing - original draft; J.R-P and H.C.T-T; Writing - review and editing: T.R-G. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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