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Silicon increases the production and quality of cherry tomato under different electrical conductivity levels

Silício aumenta a produção e qualidade de frutos de tomate cereja fertirrigado sob diferentes níveis de condutividade elétrica

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Highlights

Electrical conductivity management increases the production of cherry tomato.
Silicon increases the biomass of cherry tomato plants.
Fruits quality was mediated by the application of silicon.

Abstract

The addition of high nutrient concentrations to irrigation water increases its electrical conductivity by contributing to its salinity, resulting in crop yield losses. However, in cases where stress conditions are not observed, silicon can act as a biostimulant and promote vegetative growth, fruit quality, and fruit production. From this perspective, this study aimed to evaluate the effect of fertigation with different electrical conductivity levels associated with potassium silicate on the production parameters of cherry tomatoes grown in a protected environment. The study was conducted in Bom Jesus - PI, and arranged in a randomized block design with four replications and a 6 x 2 factorial corresponding to six electrical conductivity levels (1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1}) in the absence and presence of silicon (2 mmol

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L^{-1}). The variables analyzed were the number of fruits per plant, fresh and dry fruit biomass, dry biomass of stem, leaves, bunches, root, shoot, and whole plant; and chemical quality of fruits (pH, total soluble solids, titratable acidity, and the ratio of total soluble solids to titratable acidity. Silicon supplementation increased the root and shoot dry masses and improved fruits quality, thus increasing cherry tomato production (Sweet Heaven hybrid) regardless of the electrical conductivity levels.
Key words: *Solanum lycopersicum var. cerasiforme.* Biostimulant. Beneficial element.

Resumo

A adição de elevadas concentrações de nutrientes à água de irrigação promove o aumento da condutividade elétrica, deixando a solução sob condições salinas, o que acarreta perdas de produtividade das culturas. No entanto, mesmo nos casos em que as condições de estresse não são evidentes, o silício pode apresentar função benéfica como elemento bioestimulante, promovendo aumento no crescimento vegetativo, na produção e na qualidade de frutos. Neste sentido, este estudo teve como objetivo avaliar o efeito de diferentes níveis de condutividade elétrica da fertirrigação, associados ao uso de silicato de potássio nos parâmetros produtivos do mini-tomate cultivado em ambiente protegido. O estudo foi realizado em Bom Jesus - PI, em delineamento de blocos casualizados, com 4 repetições, em esquema fatorial 6 x 2, correspondendo a seis níveis de condutividade elétrica (1,0; 2,0; 3,0; 4,0; 5,0 e 6,0 dS m^{-1}), na ausência e presença de silício (2 mmol L^{-1}). As variáveis analisadas foram: número de frutos por planta, massa da matéria fresca e seca dos frutos, massa da matéria seca do caule, folhas, cachos, raiz, parte aérea e planta inteira; e qualidade química dos frutos (pH, sólidos solúveis totais, acidez titulável e relação entre sólidos solúveis totais/acidez titulável. A suplementação de silício aumenta a massa seca da raiz e da parte aérea e melhora a qualidade dos frutos, resultando no aumento da produção de tomate cereja (híbrido Sweet Heaven), independentemente do nível de condutividade elétrica estudado.
Palavras-chave: *Solanum lycopersicum var. cerasiforme.* Bioestimulante. Elemento benéfico.

Introduction

Tomato (*Lycopersicum esculentum* Mill.) is one of the most cultivated and consumed vegetables in the world. According to Food and Agriculture Organization of the United Nations [FAOSTAT] (2022), worldwide tomato production reached 186,821 million tons in 5.051 million ha in 2020. Tomato fruits have properties that favor the elimination of free radicals from the human organism and contain lycopene, an important antioxidant compound in the fight against cancer (Leong, Show, Lim, Ooi, & Ling, 2017).

In this scenario, cherry tomato production requires technologies such as protected cultivation and fertigation, which favor product quality, clean production, the efficient use of water and fertilizers, early production, and high profitability (Shamshiri, 2017). These technologies are associated with the use of substrates, which provide support for plants and an ideal environment for cultivation (Kraska, Kleinschmidt, Weinand, & Pude, 2018). However, the continuous monitoring of the soil solution through its electrical conductivity (EC) is necessary to minimize the adverse effects caused by excess salts distributed by fertigation throughout the crop cycle (Bonachela, Fernández, Cabrera, & Granados, 2018; Bezerra, Pereira, Bezerra, Cavalcante, & Medeiros, 2019).

The adverse effects caused by such conditions are related to morphological, physiological, and biochemical plant processes (Khan et al., 2019; Lima et al., 2020). For example, dry matter production decreases under high salt concentrations in the culture medium, with negative effects on photosynthesis (Alam, Tester, Fiene, & Mousa, 2021). Additionally, losses in the water-use efficiency and nutrient deficiency can also be observed (N, Ca, K, P, Fe, and Zn), causing oxidative stress due to the production of reactive oxygen species (Rehman et al., 2019). The main symptoms of toxicity due to excess salts are reduced stem height and root length, shortened internodes, wilting, chlorosis, leaf abscission, and root and leaf necrosis, potentially causing plant death (Shrivastava & Kumar, 2015; Rahneshan, Fatemeh, & Moghadam, 2018).

Silicon fertilization stands out among the widespread alternatives used to mitigate the deleterious effects caused by abiotic stresses (Li et al., 2018), the most common source of which is potassium silicate, given its high solubility (Savvas & Natatsi, 2015). Although Si is not considered as an essential plant nutrient, it is responsible for stimulating plant growth and production, protecting plants against abiotic stresses (Kurdali, AL-Chammaa, & AL-Ain, 2018), and mitigating nutritional stress (Silva G. B. D. et al., 2019; Campos et al., 2020), water stress (Kobra, Emam, Ashraf., & Arvin, 2019), and salinity (AL-Garni, Khan, & Bahieldin, 2019). The salinity caused by excess salts applied through fertigation in tomato has been a constant problem, especially for cherry tomato, a nutrient-demanding crop characterized as moderately sensitive to salt stress, resulting in reduced plant growth (Amjad et al., 2019; Alam et al., 2021).

In this context, several studies have been carried out with silicon because of the various beneficial effects of this element on plants, with emphasis on the cultivation of horticultural species such as cucumber (*Cucumis sativus* L.) (Campos, Mello Prado, Caione, Lima, & Mingotte, 2016), cauliflower (*Brassica oleracea var. botrytis* L.), broccoli (*Brassica oleracea var. italica* L.) (Barreto, Schiavon, Maggio, & Mello Prado, 2017), yellow passion fruit (*Passiflora edulis* Sims.) (G. B. D. Silva et al., 2019), and tomato (*Solanum lycopersicum* L.) (Pailles et al., 2019; Costan, Stamatakis, Chrysargyris, Petropoulos, & Tzortzakis, 2020). In general, these studies address the mitigating effect of Si under abiotic stress conditions (Khan, Latif Khan, Muneer, Kim, & AL-Rawahi, 2019). However, the biostimulating effect of Si, increasing vegetative growth and fruit production at different EC levels, especially in cherry tomato plants grown under fertigation, is still not widely reported in the literature. From this perspective, this study aimed to evaluate the effect of fertigation with different electrical conductivity levels associated with potassium silicate on the production parameters of cherry tomatoes grown in a protected environment.

Material and Methods

The experiment was conducted from September 2017 to January 2018 in a greenhouse at the Federal University of Piauí (UFPI), Campus Professora Cinobelina Elvas

(CPCE), in Bom Jesus - PI, located at the following geographic coordinates: 09º 05′ 32″ S, 44º 20′ 32″ W, and at an elevation of 277 m a.s.l. The data relative to air temperature and relative humidity during the experiment are presented in Figure 1. The climate of the region is dry and sub-humid, according to Thornthwaite's classification, with average rainfall ranging from 900 to 1200 mm year^{-1} and an average temperature of 26.5 ºC (R. M. Medeiros, Alcântara Silva, Silva Melo, Menezes, & Menezes, 2016).

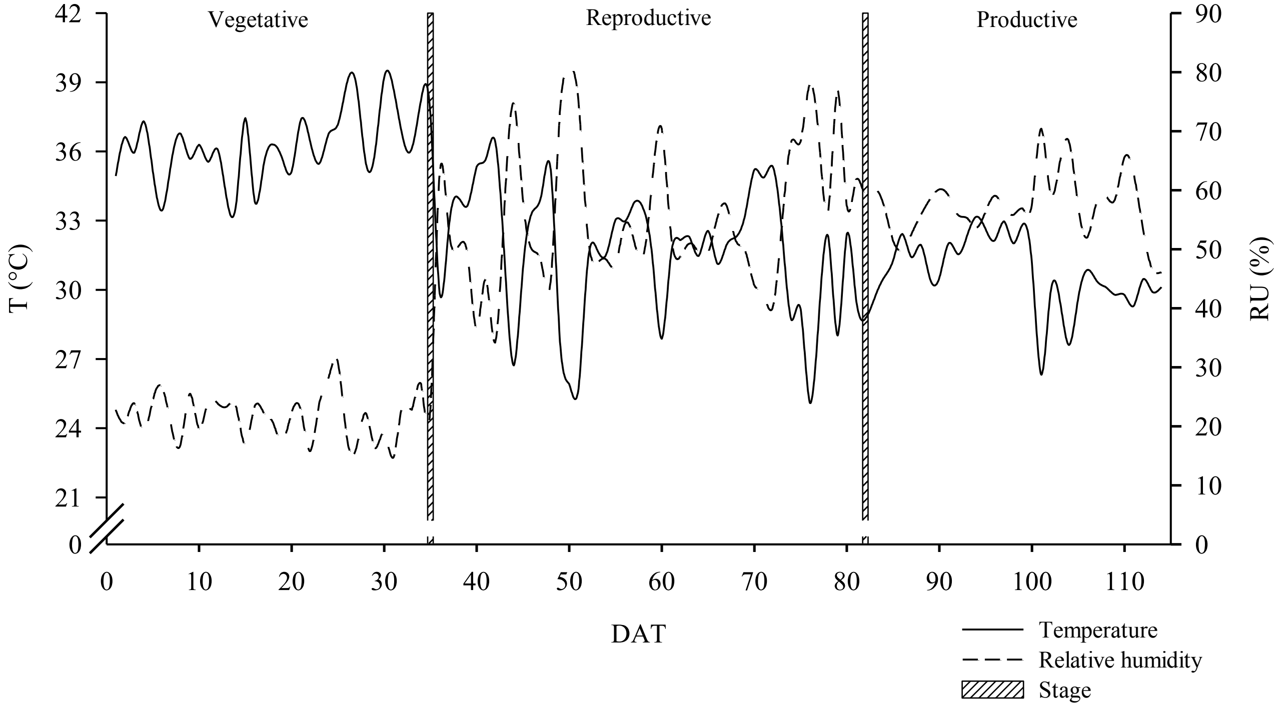


Figure 1. Mean air temperature and relative humidity inside the greenhouse during the experiment.

The experimental design was set up in randomized blocks with four replications and arranged in a 6 x 2 factorial, corresponding to six electrical conductivity levels (1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 dS m^{-1}) in the presence and absence of silicon. Potassium silicate was adopted as the source of Si at the concentration of 2.0 mmol L^{-1}. Each experimental unit consisted of a plant grown in an 8-L polyethylene pot filled with the commercial substrate Carolina Soil Padrão II®, consisting of *Sphagnum* peat, expanded vermiculite, roasted rice husk, and fertilizers (macro and micronutrients), with an electrical conductivity of 0.7 dS m^{-1} and a pH of 6.5 ± 0.25.

The content of potassium silicate used in the experiment was based on the solubility of silicic acid -(H_4SiO_4) in water, which is about 2 mmol L^{-1} at 25 ºC (equivalent to the SiO_2 concentration of 120 mg L^{-1}). Concentrations higher than 2 mmol L^{-1} cause the polymerization of silicic acid into silica (SiO_2•nH_2O) (Savvas & Natatsi, 2015).

The cherry tomato (*Solanum lycopersicum var. cerasiforme*) hybrid Sweet Heaven ("grape" type) was cultivated in a greenhouse measuring 36 m², covered by 150-mm-thick transparent polyethylene film, and protected on the sides with a white 30% polypropylene shade net (Sombrite®). The seedlings were propagated in 128-cell expanded polystyrene trays filled with the commercial substrate Carolina Padrão II® and were transplanted to pots when they had four or five true leaves, which occurred 25 days after sowing.

The seedlings were treated with a solution composed of Connect® and Carbomax® in the proportion of 1 mL of compound to 1 L of water to avoid pests and diseases before transplanting. Twenty days after transplanting, the plants were trained with smooth wire No. 14 attached to the wooden frame of the greenhouse at an approximate height of 2 m and were conducted vertically using nylon strings. The lateral shoots that emerged at the base of the stems were removed every week using pruning shears, whereas those located above this region were kept. After removing the shoots, Carbendazin® was applied for disease control, whereas the commercial product Terranim® was applied pest control in a solution equivalent to 4 mL L^{-1}.

The experiment used a drip irrigation system with pressure-compensating emitters and a nominal flow rate of 4 L h^{-1} attached to irrigation rows (16-mm-diameter polyethylene pipes). Valves were installed at the beginning of each row, allowing different nutrient concentrations according to each treatment.

The fertigation solutions (treatments) were stored in PVC tanks (100 L): tank 1 corresponded to fertigation without Si, and tank 2 corresponded to fertigation with Si. The system also had a 0.5-hp pump with a manometer and filtration systems. Fertigation was performed three times a week, and the silicon solution was applied every day. The irrigation system was evaluated under the operating pressure of 1 kgf cm^{-2} and showed a water distribution uniformity coefficient of 98.2%.

Fertilizers were applied along with irrigation water according to the methodology described by D. R. G. Silva and Lopes (2011) by considering the solubility (g L^{-1} at 20 °C) and salt index (1.0 g L^{-1} at 25 ºC) of the salts used: ammonium sulfate, calcium nitrate, potassium nitrate, monoammonium phosphate, magnesium sulfate, and potassium silicate.

Fertigation without Si was based on the crop absorption rate proposed by Alvarenga (2013). The reference considered for the chemical composition of fertilizer salts was the cherry tomato fertilization recommendation described by Moraes (1997). The sources of macronutrients used were MAP - monoammonium phosphate, potassium nitrate, calcium nitrate, and magnesium sulfate. The applied contents of these macronutrients are detailed in Table 1.

Table 1
Sources and nutrient contents applied via fertigation during cherry tomato cultivation according to different electrical conductivity levels and (Si) absence or presence of silicon

Electrical conductivity levels	Without Si				
	$NH_4H_2PO_4$	KNO_3	$Ca(NO_3)_2$	$MgSO_4$	Total
	g per plant				
1.22 dS m^{-1}	15.88	33.85	22.49	15.21	87.44
2.13 dS m^{-1}	31.76	67.71	44.99	30.42	74.87
3.12 dS m^{-1}	47.64	101.56	67.48	45.63	262.31
4.07 dS m^{-1}	63.52	135.41	89.98	60.84	349.75
5.12 dS m^{-1}	79.40	169.26	112.47	76.05	437.19
6.07 dS m^{-1}	95.29	203.12	134.96	91.26	524.62
Total	333.50	710.90	472.40	319.40	1,736.20

	With Si						
	SO_3NH_4	$NH_4H_2PO_4$	KNO_3	$Ca(NO_3)_2$	$MgSO_4$	K_2SiO_3	Total
	g per plant						
1.22 dS m^{-1}	0.95	15.88	31.24	22.49	15.21	1.925	87.70
2.13 dS m^{-1}	0.95	31.76	65.10	44.99	30.42	1.925	175.14
3.12 dS m^{-1}	0.95	47.64	98.95	67.48	45.63	1.925	262.57
4.07 dS m^{-1}	0.95	63.52	132.80	89.98	60.84	1.925	350.01
5.12 dS m^{-1}	0.95	79.40	166.65	112.47	76.05	1.925	437.44
6.07 dS m^{-1}	0.95	95.29	200.51	134.96	91.26	1.925	524.90
Total	5.7	333.50	695.25	472.40	319.40	11.550	1,837.77

Micronutrient applications were performed by foliar spraying at weekly intervals based on a commercial product with a solid mixture EDTA - chelated nutrients containing Cu, Mn, Zn, B, and Mo, respectively at 0.28, 7.5, 0.7, 0.65, and 0.3%.

The salts used in the fertigation with Si were calcium citrate, MAP - monoammonium phosphate, magnesium sulfate, ammonium sulfate, and potassium silicate. Ammonium sulfate was used at equivalent proportions in all electrical conductivity levels by maintaining the same contents of K+ in all treatments (Table 1). The electrical conductivity of the solution in the treatments without Si and with Si was predicted based on the content of dissolved salts and adjusted according to a test conducted using a portable conductivity meter.

After 120 days, the fresh fruit mass (FFM) (g per plant) was measured on an analytical balance accurate to 0.001 g. The dry masses of fruits, leaves, stems, roots, the shoot dry mass, and the total dry mass (ShDM) were obtained after drying in a forced-air oven at 65 ± 1°C for 72 hours until constant weight. Then, the masses were measured on an analytical balance accurate to 0.001 g.

Fruit physicochemical quality was analyzed by determining the pH, total soluble solids (TSS, with values in °Brix), and titratable acidity (TA, with values in %). The samples were composed of ten fruits per treatment. The relationship between total soluble solids and titratable acidity, used as a parameter to evaluate the degree of maturity of the raw material and its palatability, was measured according to the methodology established by the Instituto Adolfo Lutz (1985).

The data were tested for normality of residuals (Kolmogorov-Smirnov) and homogeneity of variances (Shapiro-Wilk). Subsequently, analysis of variance was performed with the F-test ($P < 0.05$). The electrical conductivity factor was analyzed by polynomial regression by adopting the best-fit significant model and the highest coefficient of determination, whereas the silicon factor was analyzed by comparison of means using the Tukey test at 5% probability with the statistical software Sisvar (Ferreira, 2011).

Results and Discussion

The different electrical conductivity levels significantly affected the number of fruits and fresh fruit mass ($p<0.01$) (Figures 2 A and C). With silicon application, the mean increases for these variables corresponded to 13.46 and 13.88% (Figures 2 B and D).

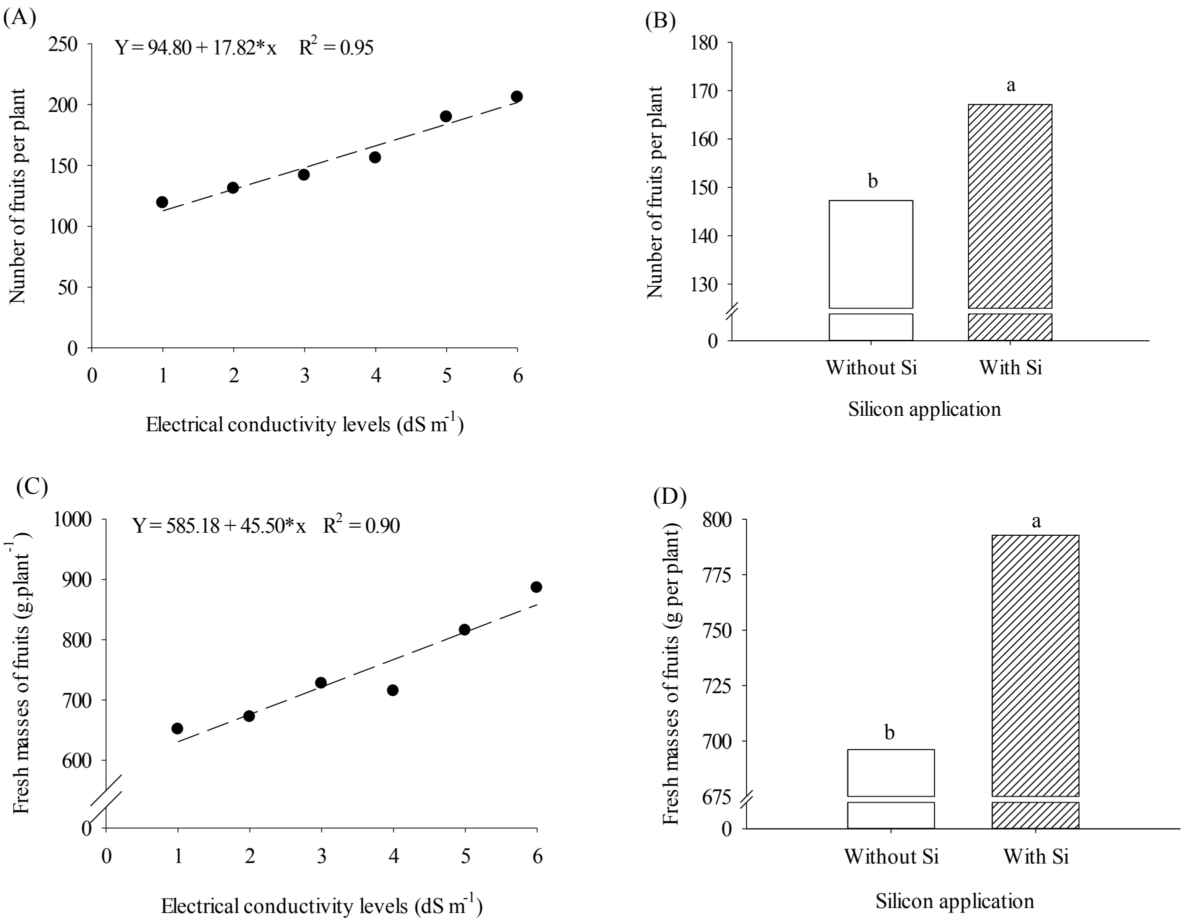


Figure 2. Number of fruits per plants (A and B) and fresh fruits mass (C and D) of cherry tomato grown under fertigation as a function of different electrical conductivity levels without and with Si.

For the number of fruits and fresh fruit mass (Figures 2 A end C) under different electrical conductivity levels via fertigation, the data fit an increasing linear model, with a maximum production of 204.72 fruits per plant and a mean fresh fruit mass of 885.18 g.

The literature reports reductions in tomato yield caused by high EC levels in the solution. For example, Amjad et al. (2019) observed reductions in tomatoes grown under salt stress conditions, and mean EC levels ranging from 4.4 to 4.5 dS m^{-1} have been reported in other studies on the crop cycle of tomato (P. R. F. Medeiros, Duarte, Uyeda, Silva, & Medeiros, 2012; Boari, Donadio, Pace, Schiattone, & Cantore, 2016). Tomato is considered moderately sensitive to salinity, with a threshold tolerance of 2.5 dS m^{-1} from which the yield is reduced per unit increase in the EC. However, tolerance may vary due to factors that can be either intrinsic (genotype, cultivar, species, etc.) or external to the plant (climate, management, etc.) and related to the phenological stage and duration of salt stress exposure (Boari et al., 2016).

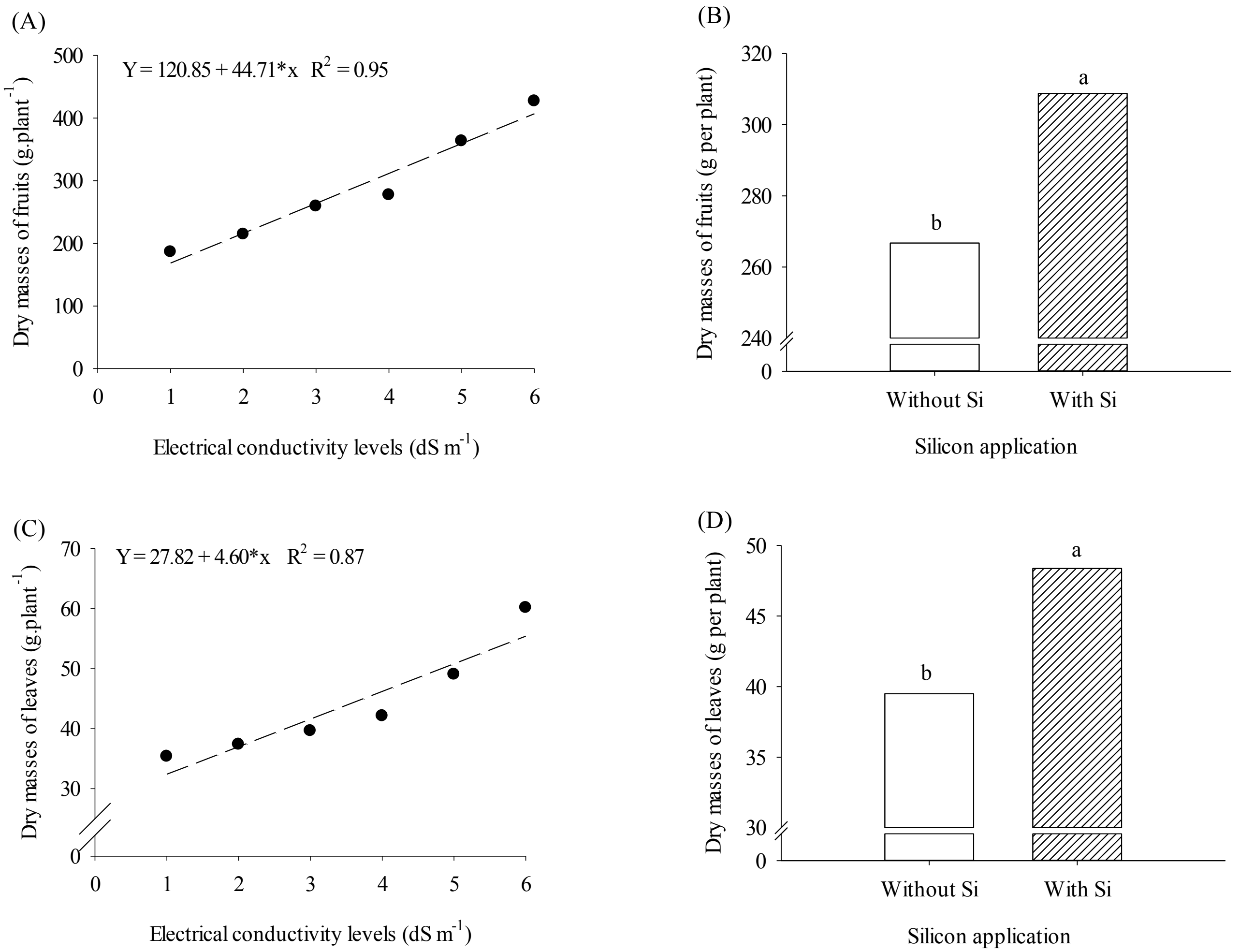
The increase in the studied variables (Figures 2 B and D) due to the addition of silicon is related to the numerous benefits of this element by increasing crop yield, resistance against pests and diseases, and mitigating the effects of potentially toxic heavy metals, salt stress, and water deficit, among others (Rodrigues, Oliveira, Korndörfer, & Korndörfer, 2011). The results of the present study are consistent with Marodin (2011), who observed increased shoot fresh mass and number of fruits in tomato plants. Overall, the beneficial effect of Si under abiotic stress conditions have also been observed in other crops, e.g., strawberry (*Fragaria × ananassa* Duch.) (Braga et al., 2009), lettuce (*Lactuca sativa* L.) (Galati et al., 2015), rice (Yan et al., 2020) and purple coneflower (Khorasaninejad & Hemmati, 2020).

The dry mass of fruits, leaves, roots, and total dry mass (Figures 3 A, C, E, and G) was significantly affected ($p<0.01$) by the EC levels tested regardless of silicon application in the nutrient solution. Moreover, the shoot dry mass showed a significant interaction between silicon application and EC, as seen in Figure 3 I. The variables mentioned above showed mean increases of 15.79, 22.45, 56.15, and 18.97%, respectively (Figure 3 B, D, F, and H), under fertigation with silicon compared to the treatment without this element regardless of the EC level.

The dry mass of fruits, leaves, stems, roots, total dry mass, and shoot dry mass (Figure 3) was positively influenced by fertigation with silicon, favoring the phytotechnical parameters and the yield of tomato fruits and agreeing with fresh fruit mass (Figure 2). Other studies have also addressed the benefits of Si in tomato. From this perspective, Marodin (2011) reported significant leaf dry mass gains in tomato as a function of Si uptake by roots and translocation to the leaves. In another study, Savvas and Natatsi (2015) observed significant dry mass gains in sweet corn, cucumber, and tomato fertigated with silicon. It should be noted that silicon application influenced the total dry mass of tomato, increasing its production by 18.97% (Figure 2H). In that case, silicon acts secondarily by favoring plant development and dry mass accumulation.

Similar results have been found by Braga et al. (2009), who observed an increase in the total dry mass of the commercial tomato hybrid Raf fertigated with Si sources.

In another study, AL-Huqail, Alqarawi, Hashem, Malik, & ABD_Allah (2017) observed that Si supplementation using potassium silicate (2 mM L^{-1}) in *Acacia gerrardiim* Benth favored increased the total dry mass by 12.57% and the root dry mass by 20.70%. G. B. D. Silva et al. (2019) also observed that 2 mmol L^{-1} of Si increased the root and shoot dry mass of yellow passion fruit seedlings under ammoniacal stress conditions, corroborating the plant growth results of the present study. Thus, the positive production results obtained with cherry tomato in the presence of Si (Figures 2 and 3) confirm the important role of this nutrient in plant-environment relations by providing better conditions for the crop to withstand climatic, edaphic, and biological adversities, increasing its production quality.



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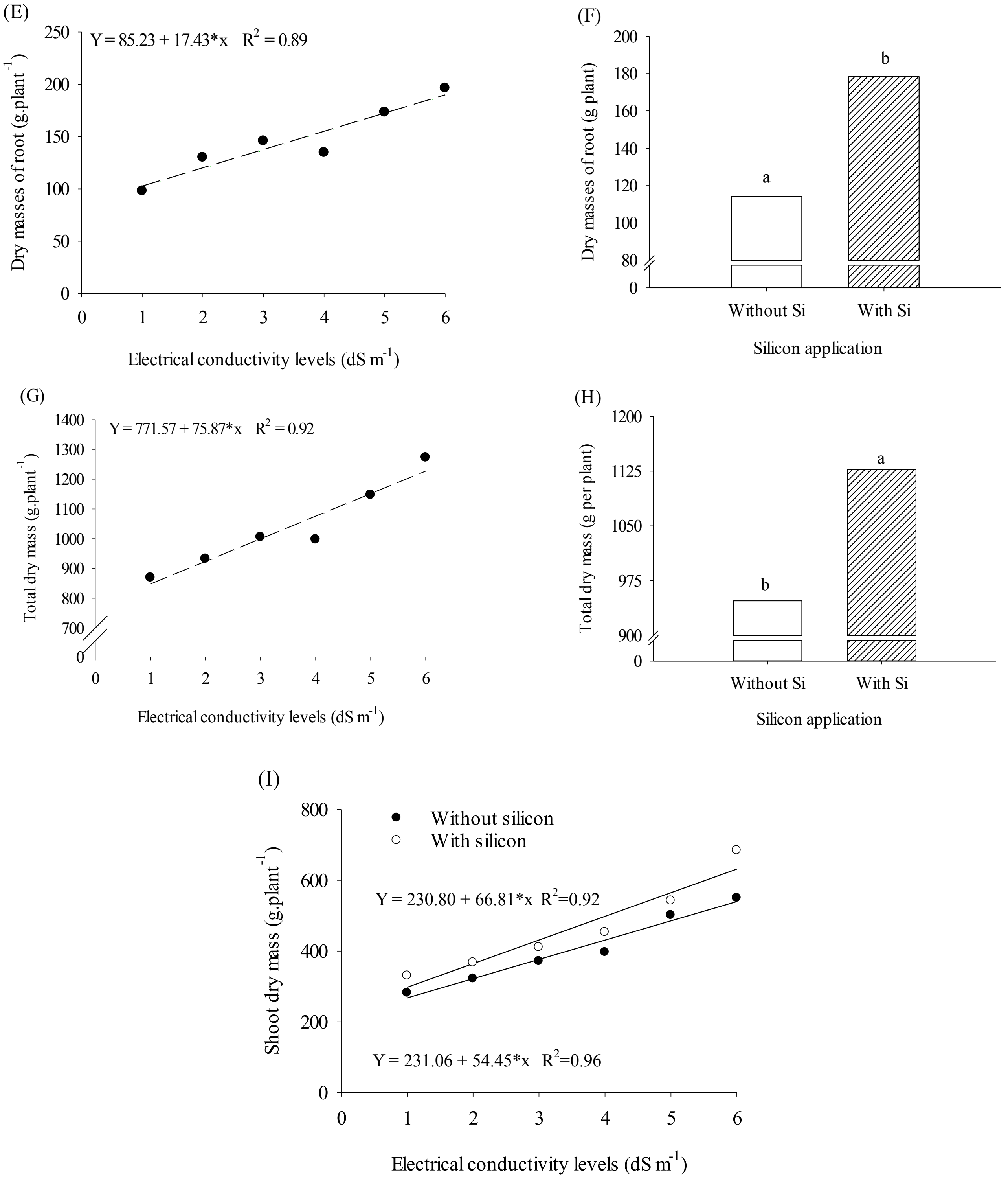

Figure 3. Dry mass of fruits (A and B), leaves (C and D), roots (E and F), total dry mass (G and H), and shoot dry mass (I), of cherry tomato grown under fertigation as a function of different electrical conductivity levels without and with Si.

With regard to the essentiality of certain elements for plant development, although silicon is not considered essential for crop development, its beneficial effects are widely reported (Marschner, 1995) as an attenuator of abiotic stress. The most prevalent use of Si in agriculture is its application as a fertilizer, common in rice and sugarcane, promoting significant gains in yield.

The increased dry mass values under fertigation with silicon are due to the hypothesis that the increase in the photosynthetic rate stimulated by Si in the plant tissue improve the uptake and mobility of macro and micronutrients essential for plant development (Safdar et al., 2019; Campos et al., 2020). From this perspective, it is suggested that, due to its structural role, Si promotes the formation of a physical layer on the leaves that helps reduce perspiration while favoring the maintenance of stomatal opening, thus contributing to the stability of the photosynthetic process under abiotic stress conditions (Ma & Yamaji, 2006).

Tomato is classified as a non-Si accumulator (< 0.5% of Si in dry matter) due to the low concentration of this element in the plant tissue (Mitani & Ma, 2005). However, studies have revealed that Si can increase the growth and production of cherry tomato (Toresano-Sánchez, Valverde-García, & Camacho-Ferre, 2012) and improve the photosynthetic activity of tomato plants (Cao, Ma, Zhao, Wang, & Xu, 2015), including under salt stress conditions (Zhu & Gong, 2014). Thus, these results elucidate that the regulation of Si in non-accumulating plants such as tomatoes is also important, especially in studies with high EC levels under fertigation.

Current investigations on the mitigating effects of Si on salt stress in plants through high salt concentrations in solution have been largely restricted to monocotyledons considered to be Si accumulators (>1.0% of Si in dry matter). Studies on the efficiency of silicon absorption in plants still have no conclusive results. However, other studies have highlighted the efficient CO2 assimilation in CAM plants of the family Poaceae, with high rates of Si uptake and conversion. Nonetheless, it has been widely reported that the exogenous supply of Si to crops such as cucumber, zucchini, beans, tomato, and roses improves their growth and yield (Li et al., 2018; Campos et al., 2020). In this scenario, due to the gains in yield, Si has been used as a vegetable biostimulant through fertigation in modern agriculture.

There was an increasing linear response for the variables of fruit dry mass, leaf dry mass, root dry mass, and total dry mass under high EC levels (Figures 3 A, C, E, and G). As the levels in fertigation increased, these variables increased by 36.99, 16.53, 20.45, and 9.83% per unit increase in salinity. Therefore, the EC levels up to 6 dS m^{-1} caused no negative effects on these variables, confirming that this species has mechanisms of tolerance to the EC levels used in this study. Similar results were observed by Pailles et al. (2019), who evaluated rustic species of tomato (accessions *S. cheesmaniae* and *S. galapagense*) and found higher efficiency and ability of these species to maintain growth (based on dry mass) during salt stress under high electrical conductivity (15 dS m^{-1} for 10 days), compared to commercial varieties (*S. lycopersicum*).

The interaction for shoot dry mass observed between Si and EC (Figure 3 I) suggests that the excess of fertilizer salts is also attenuated when using Si, thus allowing the use of nutrients available to plants without compromising their development, as observed in the results obtained for total dry mass (Figure 3 G). Therefore, the plants subjected to the EC factor fertigated with potassium silicate showed superiority at all EC levels compared to the absence of Si. Fertigation with silicon increased the shoot dry mass by 11.7% at the highest salinity level (Figure 3I). Moreover, silicon application contributes to the homeostasis of elements, favors gas exchange attributes and osmotic adjustment, regulates the synthesis of compatible solutes, and stimulates antioxidant enzymes and gene expression in plants (Li et al., 2018). In addition, Si application reduces sodium uptake and translocation of (Na^+) and increases the uptake and translocation of K^+ under salt stress. However, these mechanisms vary according to the species, genotype, growth conditions, and stress duration, among other factors (Rios, Martínez-Ballesta, Ruiz, Blasco, & Carvajal, 2017).

More specifically, it is known that high EC levels confer salinity to the solution, and one of the factors that contribute to mitigating salt stress and favors the accumulation of plant biomass is the deposition of Si in the form of phytoliths or silica in different plant organs. Under saline conditions, such as those caused by Na^+, the deposition of this element can be observed below the cell walls, in which the Si molecules bind to Na^+ and allow an increase in K^+ uptake and a reduction in Na^+ transport to the upper regions of the plant (Khan et al., 2019). In turn, the ionic balance is favored, and, at the slightest sign of stress, plants emit more effective responses, e.g., eliminating reactive oxygen species such as hydrogen peroxide (H_2O_2) and hydroxyl (OH^+), and other responses mediated by the enzymatic and non-enzymatic antioxidant defense system (Abdelaal, Mazrou, & Hafez, 2020). Furthermore, silicon fertilization also influences plant architecture and increases leaf exposure to light, thus favoring photosynthesis (Siddiqui et al., 2018).

With regard to the chemical quality of fruits, a significant quadratic response ($p<0.01$) was observed for pH and TSS under high EC levels (Figure 4 A and C), whereas there was a significant interaction between EC and Si addition for TA (Figure 4 E). In the presence of Si, the TSS and TSS/TA ratio increased by 11.67 and 31.33% (Figure 4 D and F), respectively.

Characteristics such as pH, TSS, and TA are important quality parameters for the fresh fruit market and the processing industry (Leogrande, Lopedota, Montemurro, Vitti, & Ventrella, 2012). These results suggest that Si contributes to water loss and is one of the main causes of tissue deterioration, resulting in appearance changes and loss of texture and nutritional value (Carneiro, Souza, Rodrigues, & Mapeli, 2015). Fertigation with Si reduced fruit transpiration and significantly contributed to fruit quality (Figures 4 D and F). Similar results were observed by Cliff, Li, Toivonen and Ehret. (2012) and Costan et al. (2020) for the variables of total soluble solids (°Brix) and titratable acidity (%) in studies conducted with tomato, in which Si positively contributed to these traits. Furthermore, when analyzing the efficacy of Si application in strawberry, Figueiredo et al. (2010) reported increased contents of total sugars and glucose, indicating a higher ºBrix content in the fruit pulp, corroborating the present study.

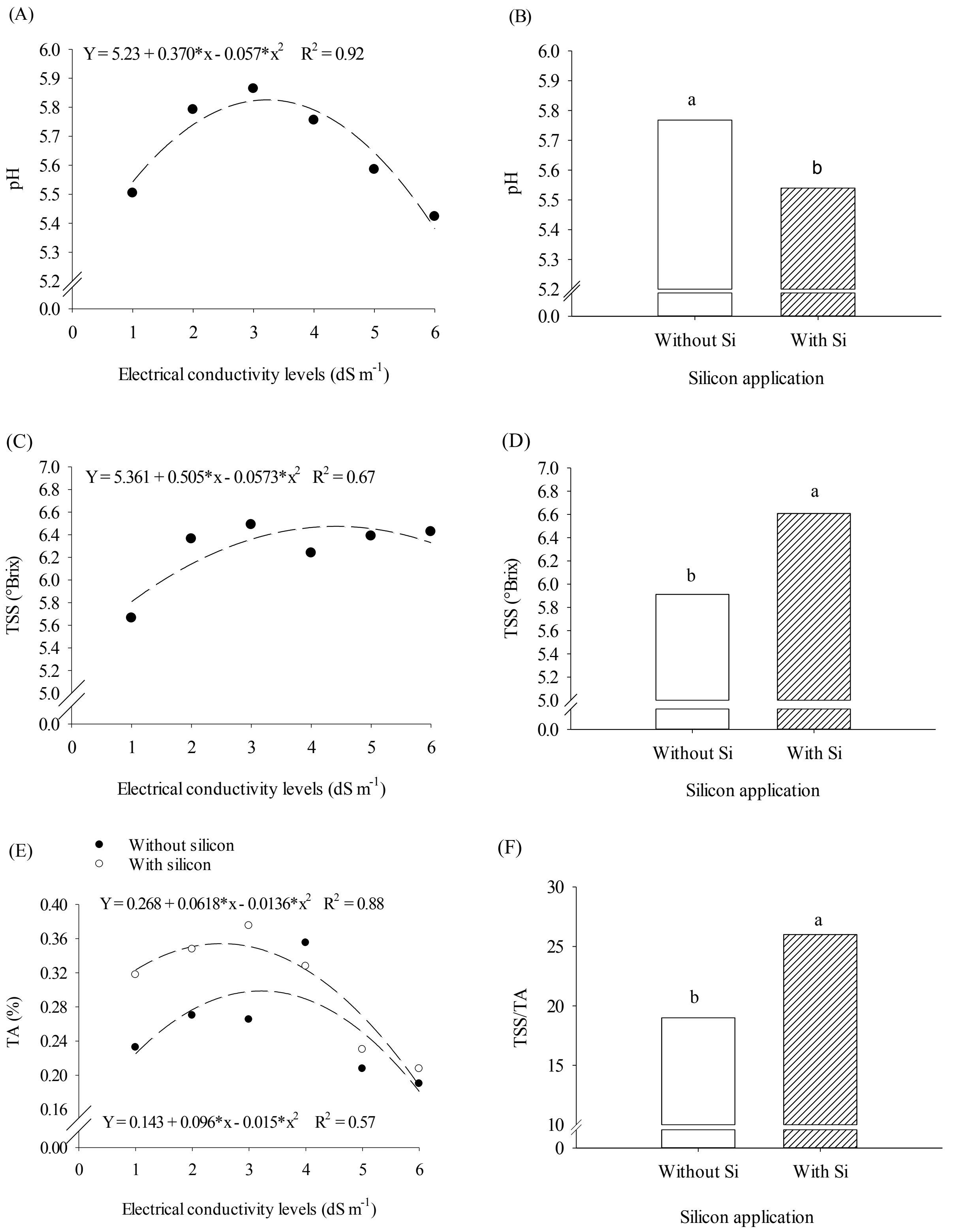

Figure 4. pH (A and B), total soluble solids, TSS (C and D), titratable acidity, TA (E), and TSS/TA ratio (F) of cherry tomato fruits grown under fertigation as a function of different electrical conductivity levels without and with Si.

The increment in the EC levels negatively affects the chemical quality of fruits, reducing the pH and TSS variables from the levels of 3.24 dS m^{-1} and 4.40 dS m^{-1} (Figure 4 A and C), respectively. The addition of salts promotes an osmotic effect. However, when this effect exceeds the tolerance level of plants, there may be functional disorders in the gas exchange and nutritional imbalance, which can be observed in the reduction of fruit chemical quality at the highest EC levels due to the accumulation of salts. Similar results were reported by Dias et al. (2010), in whose study, the increase in the salinity of the nutrient solution decreased the chemical quality of melon fruits.

Figures 4 A shows the reduction in fruit pulp pH as the EC levels increased from 3.24 dS m^{-1}. Regardless of the EC, the Si added to the culture medium moderately reduced the pH compared to tomato cultivation in the absence of this element (Figure 4 B).

A similar situation was observed by Figueiredo et al. (2010), who observed pH reductions in the pulp of strawberries fertigated with Si, thus increasing pulp acidity. This attribute is desirable for fruits intended for fresh consumption, in which case, a slightly acidic pH is more acceptable (Figueiredo et al., 2010). In this study, the titratable acidity decreased at EC levels higher than 2.22 dS m^{-1} and 3.20 dS m^{-1} (Figure 4 E) in the absence and presence of Si, respectively, reaching maximum titratable acidity at 0.34% and 0.29%, respectively. On the other hand, at the highest EC levels, the presence of silicon reduced the titratable acidity of tomato fruits (Figure 4 E), contributing to an increase in the TSS/TA ratio (Figure 4F), which corresponds to fruit flavor and favors greater acceptance by the consumer market.

Similar results were obtained by Tesfay, Bertling and Bower (2011), Nascimento et al. (2013), and Silva, Medeiros, Santos, & Gomes (2013), who observed the influence of silicon on the production and quality of fruits grown under salinity, positively influence the TSS/TA ratio. In another study, Zushi and Matsuzoe (2017) evaluated variables referring to the quality of tomato fruits (TSS, pH, TA, and the TSS/TA ratio) and observed a significant correlation with the increase in salinity levels, identifying positive effects related to these characteristics when plants were subjected to treatments with a silicon source. The results mentioned above confirm that Si has a beneficial effect on the growth parameters of tomato plants fertigated with solutions with high nutrient concentrations and, consequently, high electrical conductivity.

Conclusions

Silicon supplementation increases the root and shoot dry mass and improves the fruit quality of cherry tomato. Silicon increases cherry tomatoes production regardless of the electrical conductivity level.

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