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Silicon in the management of bacterial wilt in three tomato varieties

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Abstract

The effect of silicon (Si) supplementation on tomato seedling production of 'Santa Clara', 'TY 2006' and 'Yoshimatsu 4-11' cultivars (cvs.) was evaluated, aiming at the management of bacterial wilt caused by *Ralstonia solanacearum* (Rs). Seedlings of the three cvs. were produced in substrate without silicon (-Si) or with 3 g of calcium silicate/kg of substrate (+Si) and transplanted to soil with Rs (+Rs). The resistance components evaluated for 15 days were: incidence (INC) and severity (SEV), with calculation of the bacterial wilt index (BWI) and area under the disease progress curve (AUDPC). Additional variables analyzed included: plant growth, fresh and dry mass, reactive chlorophyll index, Si content in leaf tissues and Rs population in the stem. The enzymatic activities of phenylalanine ammonia-lyases (PAL), β-1,3 glucanases (GLU) and peroxidases (POX) were measured in the three cultivars produced in substrates (+Si) and (-Si) at the times: 0 to 96 h after transplanting. Si supplementation in the 'Santa Clara' and 'TY 2006' cultivars led to a reduction in the disease evaluated by SEV (33.2 and 42%) and BWI (21.7 and 10%), respectively. Si supplementation in the substrate did not affect growth, chlorophyll index, Si accumulation in the leaf or the Rs population in the stem tissues. Higher PAL and GLU enzymatic activity was observed at some moments in the three cultivars. Thus, tomato seedling production in substrate with Si can be a component in bacterial wilt management.

Keywords: calcium silicate, control, *Ralstonia solanacearum*

Introduction

The tomato plant (*Solanum lycopersicum* L.) is a vegetable crop belonging to the Solanaceae family that has added economic and nutritional value. Tomatoes are recognized worldwide as a healthy food which are part of the human diet due to their high vitamin, mineral and bioactive compound levels (Collins et al., 2022).

Despite its importance, tomato crops are often challenged by phytosanitary issues (Zhou et al., 2018). In this sense, bacterial wilt caused by *Ralstonia solanacearum* stands out among the pathogens that affect tomato plants, since its infection causes significant losses in crops, reducing productivity and income for farmers (Hong et al., 2018).

As it is a pathogenicity that affects vascular tissue, methods have been used to mitigate its effects, such as copper fungicides, cultural practices and soil fumigation (Zheng et al., 2024). However, none of the strategies used have generated successful control, as they are slow-response practices that increase the pathogen's resistance over time (Du et al., 2019).

Furthermore, its dissemination mainly occurs through the soil, where the pathogen can survive in the absence of a host, establishing latent infections in spontaneous plants, making its elimination more difficult (Wang et al., 2019).

The development of resistant varieties has emerged as an effective, economical and environmentally friendly approach. In this sense, breeding to acquire resistance involves identifying sources which have this characteristic and continuous screening of the phytopathogen, seeking to provide a long-term efficient solution (Yadav et al., 2023).

Although genetic resource techniques are effective control measures, they take time until a resistant cultivar is released. Thus, inducing this characteristic

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in the plant through management tactics may be an alternative to mitigate the damage caused by this pathogen in tomato crops.

Research work has focused on studying the potential use of silicon as an agent to induce resistance to biotic and abiotic stresses by strengthening the plant cell structure and increasing the production of antimicrobial substances, activated by signaling defense-related genes (Johnson et al., 2021; Singh et al., 2021).

Silicon application to the soil was responsible for inducing resistance in rice plants against *Scirpophaga incertulas* (Panda et al., 2024), in avocado with root rot caused by *Phytophthora cinnamomi* (Rands) (Álvarez et al., 2023), as well as for reducing the damage caused by *Phytophthora infestans* in potatoes through foliar application (Xue et al., 2021).

In view of the above, the objective of this study was to evaluate the effect of silicon supplementation on tomato seedling production of the 'Santa Clara', 'TY 2006' and 'Yoshimatsu' cultivars aiming toward managing bacterial wilt caused by *Ralstonia solanacearum*.

Material and Methods

Isolation, inoculum preparation and soil infestation

The *Ralstonia solanacearum* isolate UNEB01 (Rs) used in the experiment was obtained from tomato plants with severe bacterial wilt symptoms from a production area in the municipality of Petrolina, PE, Brazil (09° 03' 312'' S; 040° 22' 38.7'' W). Pathogenicity was confirmed by applying Koch's postulates to the 'Santa Clara' cultivar tomato plants. The Rs isolate was identified and characterized by the multiplex PCR technique (Pmx-PCR) with the Nmult:21:1F, Nmult:21:2F, Nmult:23:AF, Nmult:22:InF, Nmult:22:RR, 759 and 760 primers.

The bacterial suspension used in the experiments was prepared from the Rs culture in Triphenyl Tetrazolium Chloride medium for 48h at 28°C. Mucoid, irregular and white colonies were transferred to sterile distilled water (SDW) and the suspension concentration was adjusted to 5 x 10^8 CFU/mL in an Analyser 500 spectrophotometer.

The soil used in the experiments was collected on the campus of the Department of Technology and Social Sciences at the State University of Bahia (DTCS/UNEB) and subjected to chemical analysis, presenting the following characteristics: pH in water = 6.81; Ca^{+2} = 4.30 cmolc dm^{-3}; Mg^{+2} = 1.10 cmolc dm^{-3}; Na^{+} = 0.10 cmolc dm^{-3}; K^{+} = 0.51 cmolc dm^{-3}; P^{+3} = 44.53 mg dm^{-3}; N^{+} = 0.99 g Kg^{-1}; Al^{+3} = 0.00 cmolc dm^{-3}; $H^{+} + Al^{+3}$ = 0.00; OM = 0.65%; Sb = 6.01 mg dm^{-3}; T = 6.01 mg dm^{-3}; V = 100%. This soil was mixed with sand (2:1) (v/v) and autoclaved for 2 h successively at 24 h intervals for seven days.

The bacterial suspension was added to the previously autoclaved soil (40 mL/kg of soil), uniformly mixed and incubated in plastic trays covered with aluminum foil for 72 h on a bench in a greenhouse at a temperature of 28±2°C and relative humidity of 80±2%.

Silicon in the substrate for tomato seedling production

Calcium silicate ($CaSiO_3$) containing 60% silicon oxide (SiO_2) and 40% calcium oxide (CaO) (Vetec Química Fina Ltda.) was incorporated at a 3 g/kg dose using Tropstrat HT Hortaliças (Vida Verde Ltda.) commercial substrate and the calcium contents for treatments without Si addition were completed with calcium carbonate ($CaCO_3$) containing 40% calcium (Sigma-Aldrich Brasil Ltda.), so that the only variation source was the addition of SiO_2. The substrate was incubated in transparent plastic bags on a greenhouse bench at room temperature (30 ± 2°C), and its humidity was maintained by the addition of 100 mL of ASD/kg of substrate. The treated substrate was distributed in polystyrene trays after 25 days of incubation and planted with 'Santa Clara', 'TY 2006' and 'Yoshimatsu 4-11' tomato cultivars. The plants were transplanted to soil previously infested with Rs after 25 days of cultivation.

This experiment was conducted in a completely randomized design with six treatments and five replicates, represented by four plants each. The treatments consisted of three tomato varieties sown in substrate with and without silicon (+Si and –Si).

Chemical characteristics of silicon on substrate

Tropstrat HT commercial substrate with the following composition was used: N^{+} = 5.80; P^{+3} = 1.65; K^{+} = 14.50; Ca^{+2} = 10.80; Mg^{+2} = 10.50; C^{+4} = 215 (g/kg) and B^{+3} = 5.00; Cu^{+2} = 4.00; Fe^{+3} = 238.00; Mn^{+2} = 169.00; Zn^{+2} = 36.00; Na^{+} = 290.00 (mg/kg) and pH in water = 6.20. SiO_2 was incorporated into the substrate and the contents of the following nutrients were then determined after 25 days: N^{+}, P^{+3}, K^{+}, Ca^{+2}, Mg^{+2}, C^{+4}, B^{+3}, Cu^{+2}, Fe^{+3}, Mn^{+2}, Zn^{+2} and Na^{+}, as well as the pH, organic matter content and moisture content. The silicon contents in the substrate were determined by the acetic acid method (CH_3COOH). Three single samples were collected in each treatment (-Si and +Si) and mixed to form a composite sample, which was divided into four subsamples, representing the replicates.

Silicon in bacterial wilt resistance components, tomato growth and Si levels in plants

The 'TY 2006' (Seminis Ltda.), 'Santa Clara' (Feltrin Ltda.) and 'Yoshimatsu 4-11' (Instituto Nacional de Pesquisas da Amazônia) tomato cultivars were

selected because 'Santa Clara' is a susceptibility pattern (4) and 'TY 2006' and 'Yoshimatsu 4-11' are respectively considered moderately tolerant and tolerant to bacterial wilt.

Their seeds were sown in polystyrene trays containing commercial Tropstrat HT Hortaliças substrate with the treatments +Si and –Si, and the seedlings were grown for 25 days after emergence. The seedlings were then transplanted into 300 mL plastic pots containing infested soil (+Rs). Soil moisture was maintained at field capacity by daily irrigation with the addition of approximately 200 mL of water/pot.

After transplantation, the plants were grown for 15 days in greenhouse conditions at a temperature of 28±2°C and a relative humidity of 80±2%. The plants were evaluated daily for the presence of characteristic symptoms of bacterial wilt (i.e. incidence of the disease - INC). Disease severity (SEV) was assessed every three days based on a descriptive scale from 0 to 4, in which: 0 = absence of symptoms; 1 = plant with 1/3 of wilted leaves; 2 = plant with 2/3 of wilted leaves; 3 = plant completely wilted; and 4 = dead plant. The data obtained were used to determine the following components of disease resistance: bacterial wilt index (BWI) at 15 days, calculated according to McKinney (1923); and area under the disease progress curve (AUDPC), developed by Shaner & Finney (1977). After these assessments, plant growth was assessed based on height (cm) and fresh and dry biomass (g). A value 0 was assigned to the analyzed variables for plants that died due to bacterial wilt.

Next, height measurements were taken with a tape measure, and the plants were cut close to the surface of the substrate and separated into roots and shoots. After weighing to obtain the fresh mass of the biomass, the plants were placed in paper bags and kept in a forced ventilation oven for 72 hours at 60°C to determine dry mass. The dry biomass was used to determine the Si content in the leaf tissues. The material was ground in a manual mill, weighed, stored in paper bags at room temperature and sent to the Soil Laboratory of the Federal University of Uberlândia for Si analysis. The experiment in the greenhouse was installed in a completely randomized design comprising six treatments and five replicates, with four plants each. Moreover, four replicates were analyzed to determine the Si content in the tissues, each with 1 g of dry matter.

Silicon in the reactive chlorophyll index

A portable electronic chlorophyll meter (ClorofiLog, Falker) was used to take three measurements of the reactive chlorophyll index at 5, 10 and 15 days after transplanting. Four leaves of each plant were analyzed randomly. Readings were taken in the absence of sunlight to avoid deactivating photosynthetic transport.

Population of R. solanacearum in silicon-treated tomato plants

First, four samples were randomly collected from the stem of each treatment (from the base to 5 cm above) to quantify the Rs population in tomato stems. The tissues were weighed and treated with 70% alcohol and sodium hypochlorite in a 1:3 (v/v) ratio for 10 s, successively. They were then washed in SDW for 60s and fragmented to weigh 1 g of sample. The sample was then mixed with 50 µL of SDW, and the suspension was centrifuged for 20 min at 2400 rpm. The pellet was resuspended in 1000 µL of SDW, and the resulting suspension was serially diluted to 103 CFU/mL. Aliquots of 100 µL were subsequently collected and spread on Petri dishes containing TZC medium using four dishes per treatment. After incubation for 72 h at 28°C, typical Rs colonies on each plate were counted and the values were converted to Log (CFU/mL +1). The pathogenicity of some colonies was tested on 'Santa Clara' cv. tomato plants for confirmation.

Silicon in the enzymatic activity of tomato plants

Plant tissue was collected at five time points to analyze enzymatic activity: zero h (one hour before transplanting), 24h, 48h, 72h and 96h after transplanting. Each sample consisted of one leaf per plant from each replicate in all treatments. The samples were placed in plastic bags, identified, frozen and stored in a freezer at -16°C for analysis of phenylalanine ammonia-lyases (PAL, EC 4.3.1.24), β-1,3 glucanases (GLU, EC 3.2.1.39) and peroxidases (POX, EC 1.11.1). In turn, each sample was weighed and ground in a mortar over an ice bucket to prepare the enzymatic extracts. The phenylalanine ammonia-lyase activity was determined using phenylalanine as a substrate, whose reaction results in forming trans-cinnamic acid and the activity was read in a spectrophotometer at 290 nm and compared with trans-cinnamic acid standards. The β-1,3–glucanase activity was determined according to Guimarães et al. (2010), and read in a spectrophotometer at 480 nm and compared with glucose standards. The glucose standard curve used had the following concentrations: 0, 5, 10, 20, 40, 80, 160 µg/mL. Finally, peroxidase activity was determined by the oxidation of guaiacol to tetraguaiacol in the presence of hydrogen peroxide (Zeraik et al., 2008), and read in a spectrophotometer at 480 nm.

Statistical analysis

All experiments were conducted twice to determine the consistency of the results. Since there were no differences between them (P≤0.05), the data were evaluated as replicates in time. The assumptions for analysis of variance (ANOVA) were verified using the Shapiro-Wilk and Levene tests in the Statistix 9.0 program. The means were compared by the student's t-test (P≤0.05) for substrate chemical characteristics, bacterial wilt resistance components, chlorophyll content in shoots, Si content in shoots, Rs population in tissues and enzyme activity. The LSD test (P≤0.05) was used for plant growth data. All statistical analyses were performed in the STATISTIX® program (version 9.0, Analytical Software, Tallahassee, USA).

Results and Discussion

Silicon in the chemical characteristics of the substrate

The contents of some nutrients were significantly altered 25 days after adding Si to the substrate (P≤0.05) (**Table 1**). More specifically, B^{+3}, Zn^{+2}, Mn^{+2} and Na^{+} increased from 5.21 to 9.02, from 36.00 to 48.98, from 169.00 to 207.00 and from 260.98 to 290.00 mg/Kg of substrate, respectively. In addition, the K^{+} and Cu^{+2} contents were significantly reduced from 15.35 to 14.50 and from 3.71 to 1.98 mg/Kg, respectively. The other nutrients (N, P, Mg^{+2}, Ca^{+2} and Fe^{+3}) remained unchanged after Si addition. The substrate pH was significantly increased (P≤0.05) by Si addition, changing from 6.20 to 6.66 (Table 1).

Supplementing the substrate with silicon increased the Boron (B), Zinc (Zn) and Manganese (Mn) micronutrient levels. An adequate supply of these nutrients to plants is essential to ensure successful production, since they are involved in several photosynthetic processes and enzymatic activities, such as B, which is closely related to photosynthesis and enzyme synthesis (Sahu et al., 2020).

In addition, absorption of these nutrients through silicon application enables plants to activate biochemical responses to biotic and abiotic stresses, even for those that absorb considerably smaller amounts from the soil (Putra et al., 2020).

The Na^{+} content increased by 10% in the substrate supplemented with Si, which can be considered advantageous, although both Na^{+} and Si meet the essentiality criteria in the mineral nutrition of plants. This is because these elements (such as Na^{+}) in adequate concentrations can be beneficial to plants by acting in the enzymatic activation of ATPase with important functions in osmoregulation, absorption of macronutrients and cell permeability (Inocêncio et al., 2014).

The same occurred for the substrate (+Si) pH, which was significantly increased by 10.6%, being considered an additional beneficial effect of adding Si, since pH has a strong influence on the Si availability in the soil. This characteristic may be related to the increase in some nutrients involved in plant defense when compared to the substrate (-Si), since wider pH ranges favor this condition.

Furthermore, the only elements analyzed in this study with a significant reduction in the substrate (+Si) were Cu^{+2} and K^{+}. However, this reduction can mainly be attenuated by increasing the pH to 6.60, which can make Ca^{+2}, Mg^{+2}, P^{+3} and K^{+} ions more available to plants. Na^{+} can also partially replace K^{+} in the enzymatic activation of ATPase (Inocêncio et al., 2014).

Silicon in bacterial wilt resistance components, tomato growth and Si levels in plants

Evaluations performed 15 days after pathogen inoculation demonstrated that Si had no significant influence (P≤0.05) on bacterial wilt incidence in any of the studied cultivars (**Table 2**). The 'Yoshimatsu 4-11' cv. showed low INC (2.5%) and only in (-Si) plants; consequently, SEV, AUCPD and BWI were also very low and did not differ from the treatment (+/-S), which had a zero value for INC and other variables. The SEV, AUCPD and BWI parameters were reduced (P≤0.05) by the Si treatment in the 'Santa Clara' and 'TY 2006' cultivars, except for the AUCPD of 'Santa Clara'. The addition of Si reduced SEV and BWI in this cultivar by 33.2 and 21.7%, respectively. Moreover, the SEV, AACPD and BWI parameters were reduced by 42, 19.2 and 10% in the 'TY 2006' cv., respectively.

The effect of Si on reducing resistance components to bacterial wilt was not observed in the disease incidence, but rather in its severity, and varied

Table 1. Nitrogen (N^{+}), phosphorus (P^{+3}), potassium (K+), magnesium (Mg^{+2}), calcium (Ca^{+2}), copper (Cu^{+2}), boron (B^{+3}), iron (Fe^{+3}), zinc (Zn^{+2}), manganese (Mn^{+2}), sodium (Na^{+}) levels and pH of the substrate treated (+Si) or not (-Si) with silicon, evaluated 25 days after application.

Nutrient	Substrate	
	-Si[a]	+Si
N^{+b}	5.38a[c]	5.31[a]
P^{+3}	1.65[a]	1.83[a]
K^{+}	15.35[a]	14.50[b]
Mg^{+2}	10.03[a]	10.50[a]
Ca^{+2}	10.80[a]	11.00[a]
Cu^{+2}	3.71[a]	1.98[b]
B^{+3}	5.21[b]	9.02[a]
Fe^{+3}	230.00[a]	280.00[a]
Zn^{+2}	36.00[b]	48.98[a]
Mn^{+2}	169.00[b]	207.00[a]
Na^{+}	260.98[b]	290.00[a]
pH	6.02[b]	6.66[a]

Tabela 2. Resistance components to bacterial wilt in 'Santa Clara', 'TY 2006' and 'Yoshimatsu 4-11' tomato cultivars grown in substrate treated (+Si) or not (–Si) with silicon and evaluated 15 days after transplanting to soil infested with *R. solanacearum*.

Resistance component	'Santa Clara'		'TY 2006'		'Yoshimatsu 4-11'	
	-Si	+Si	-Si	+Si	-Si	+Si
Incidence (%)	80.90[a]	80.98[a]	30.00[a]	40.00[a]	2.50[a]	0.00[a]
Severity	2.62[a]	1.75[b]	1.50[a]	0.87[b]	0.90[a]	0.00[a]
AUDPC[b]	66.25[a]	50.98[a]	14.60[a]	11.80[b]	0.30[a]	0.00[a]
BWI[c] (%)	69.00[a]	54.00[b]	59.00[a]	53.03[b]	0.05[a]	0.00[a]

for each cultivar. The 'Santa Clara' cultivar showed the greatest disease intensity, confirming its high susceptibility, in plants grown in both (+Si) and (-Si) substrates. However, the effect of Si in this cultivar resulted in reducing SEV and BWI, which according to Ghareeb et al. (2011) indicates possible action of this element in expressing genes responsive to the presence of the bacteria. This resistance pattern to adverse conditions is due to the hardness imposed by plant tissues when they are in contact with silicate fertilizers (Moldes et al., 2016). Our results corroborate those presented by Anjos et al. (2014), who verified strong resistance of the plants to bacterial spot caused by *Xanthomonas* spp. in studying different potassium silicate concentrations in tomato plants.

Si also significantly reduced the severity of bacterial wilt (SEV, AUDPC and BWI) in the 'TY 2006' cv., considered moderately tolerant to Rs. In turn, 'Yoshimastu 4-11' cv. plants showed virtually no typical symptoms of the disease, regardless of the treatment, and these responses were consistent with those observed by Jiang et al. (2019) and Narasimhamurthy et al. (2019).

Regarding plant growth in the greenhouse, there were no significant differences (P≤0.05) between plants produced in +Si and -Si substrates 15 days after inoculation with Rs for any of the physiological variables analyzed. However, the 'Yoshimatsu 4-11' cv. showed significantly (P≤0.05) higher height, dry biomass and chlorophyll content values of 18.6 cm, 2.41 g and 32.27 nm, respectively, than the 'Santa Clara' and 'TY 2006' cultivars (**Figure 1**).

The addition of Si to the substrate did not cause any change (P≤0.05) in the Si accumulation in the leaf tissues in any of the cultivars studied, with values of up to 3.3%. This result can be explained by the fact that tomato plants are classified as non-silicon accumulators. Plants are considered accumulators when their fresh matter has 1 to 3% SiO_2 and non-accumulators when this percentage is less than 0.5% (Ma et al., 2001). The Si/g fresh matter contents in our study were less than 0.5%, considering that greater Si accumulation is not necessary when the disease reduction mechanism is resistance induction.

Even though it was not evaluated in our study, the literature reports that there is a strong interaction between

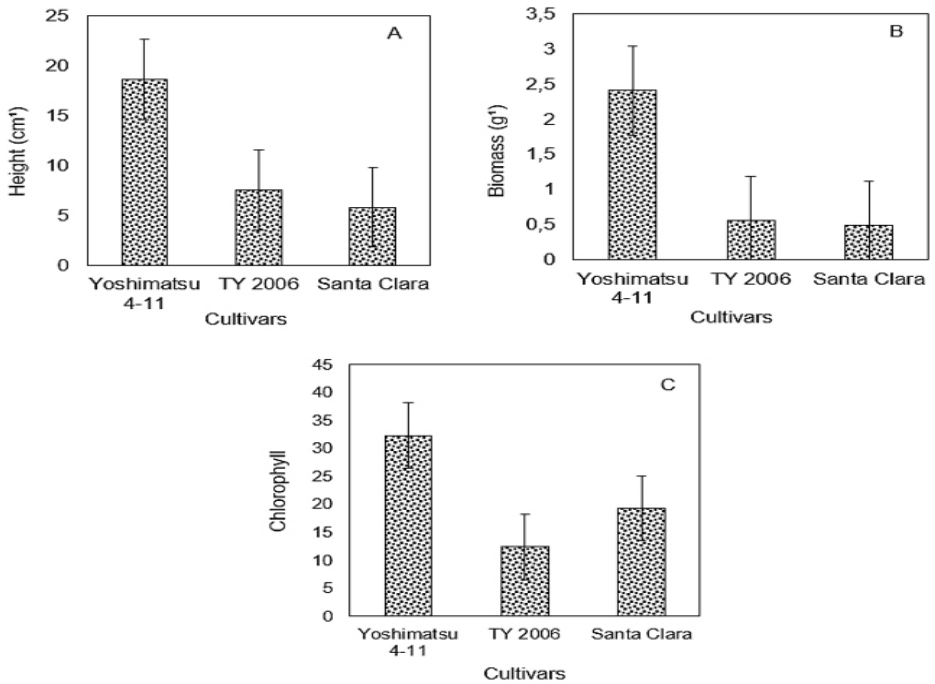

Figure 1. Growth of the 'Santa Clara' (susceptible), 'TY 2006' (moderately tolerant) and 'Yoshimatsu 4-11' (tolerant) cultivar tomato plants evaluated 15 days after transplanting into soil infested with *R. solanacearum*.

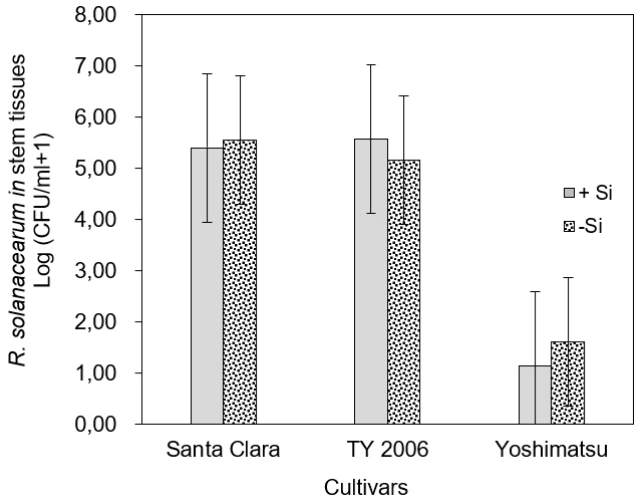

Figure 2. Population of R. solanacearum in the stem (from the base to 5 cm above) of 'Santa Clara', 'TY 2006' and 'Yoshimatsu 4-11' cultivar tomato plants grown in substrate treated (+Si) or not (–Si) with silicon and evaluated 15 days after transplanting to soil infested with the bacteria (+Rs).

silicon absorption and an increase in the root system, being considered as a plant response in preventing stresses caused by phytopathogenic infections, since this condition enables improved water and nutrient absorption, and possibly partially alleviates infection by Rs (Abozeid et al., 2017; Kim et al., 2016).

Population of R. solanacearum in tissues of tomato plants treated with silicon

Si supplementation in the substrate did not significantly affect (P≤0.05) the number of Rs colonies in the stem tissues of the three cultivars analyzed (**Figure 2**).

Colonization by Rs in plant tissues was not significantly affected by the +Si treatment in any of the three cultivars. It was observed that 'Yoshimatsu 4-11' had a lower Rs population compared to the other cultivars, indicating a possible tolerance to Rs colonization in its tissues and consequently low disease intensity.

Significant differences were observed between the Rs populations in the 'Santa Clara' (susceptible) and 'TY 2006' (moderately tolerant) cultivars compared to 'Yoshimatsu 4-11' (tolerant). This may be related to the characteristic of Si modulating the metabolism of phenolic compounds in root exudates, significantly altering the rhizosphere microbiome of tomato plants infected by Rs (Lin et al., 2020). This is mainly because the addition of Si to the plants acts as a barrier which prevents the infection of pathogens (Wang et al., 2017).

Silicon in the enzymatic activity of tomato plants

The enzymatic activity of phenylalanine ammonia-lyase, β 1,3-glucanase and peroxidase was detected in all treatments and times analyzed, but significant increases (P≤0.05) in activity due to Si treatment were only observed for the first two enzymes (**Figure 3** and **Figure 4**).

There was a significant increase (P≤0.05) in the phenylalanine ammonia-lyase activity in the three cultivars. The highest enzymatic activity in 'Santa Clara' only occurred 24 h after transplanting into infested soil (+Rs); such activity was detected in 'TY 2006' from 0 to 48

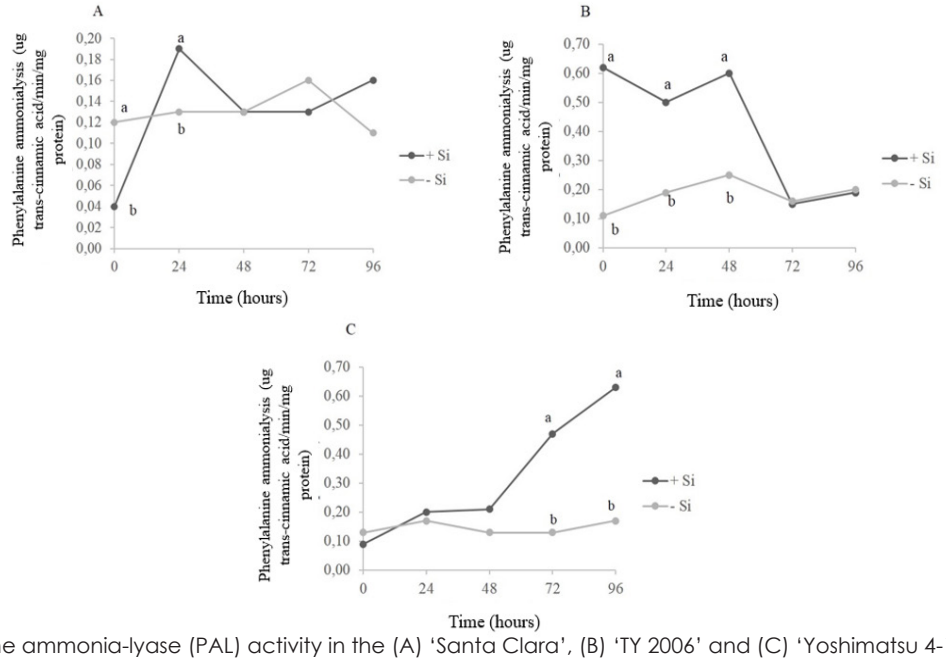

Figure 3. Phenylalanine ammonia-lyase (PAL) activity in the (A) 'Santa Clara', (B) 'TY 2006' and (C) 'Yoshimatsu 4-11' cultivar tomato plants grown in substrate (+Si and –Si), evaluated at times 0 h – one hour before inoculation, 24 h, 48 h, 72 h and 96 h after inoculation, which consisted of transplanting to soil infested with *R. solanacearum*. Means followed by the same letter for each time did not differ (P≤0.05) by the student's t-test.

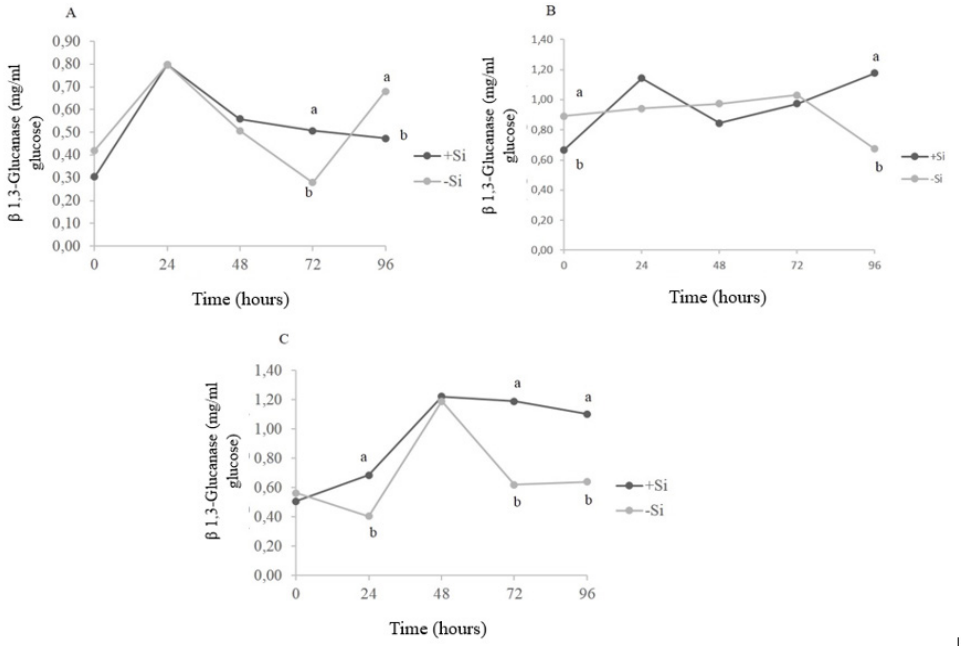

Figure 4. β 1,3-glucanase (GLU) activity in the (A) 'Santa Clara', (B) 'TY 2006' and (C) 'Yoshimatsu 4-11' cultivar tomato plants grown in substrate treated (+Si) or not (–Si) with silicon, evaluated at times 0 h – one hour before inoculation, 24 h, 48 h, 72 h and 96 h after inoculation, which consisted of transplanting to soil infested with *R. solanacearum*. Means followed by the same letter for each time did not differ (P≤0.05) by the student's t-test.

h, while the expression was observed in 'Yoshimatsu 4-11' from 72 to 96 h.

The β1,3-glucanase activity increased significantly (P≤0.05) in the 'Santa Clara' cultivar at 96 h; in 'TY 2006' at 72 h; and in 'Yoshimatsu 4-11' at 24, 72 and 96 h.

Si supplementation was effective in activating the PAL and GLU enzymes, which also varied according to the cultivar studied. Si increased the PAL enzymatic activity, with an average duration of 48 hours in the 'TY 2006' cv. The increase in Glucanase activity observed in the plants (Si+) of the three cultivars also suggests a possible relationship between the increase in this enzyme activity and the increase in the effect of Si on activating defense mechanisms. Furthermore, this behavior may also be associated with the increase in Boron in the soil after being supplemented with silicon.

The activation of antioxidant enzymes in plants is closely linked to resistance against bacterial wilt. Studies conducted by Jiang et al. (2019) report that the presence of silicon in plants is responsible for activating peroxidase, polyphenol oxidase, lipoxygenase and phenylalanine ammonia-lyase enzyme activity in tomato plants infested with Rs. Thus, the practice of inducing resistance in plants against phytopathogenic infections through the use of silicon can be an alternative to maintain the health of orchards and minimize losses caused by Rs.

Conclusion

Supplementation of commercial substrate with 3g/kg of calcium silicate reduced the severity of bacterial wilt in tomato plants of the 'Santa Clara' and 'TY 2006' cultivars. Silicon led to greater β-1,3 glucanase and phenylalanine ammonia-lyase enzyme activity, indicating action in inducing resistance to this disease. Thus, tomato seedlings produced in substrate with Si can be a control measure to be used as a component in bacterial wilt management.

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