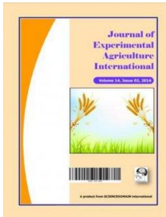

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Effect of Preharvest Application of Silicon and Saline Water on Postharvest Quality of Beet (*Beta vulgaris* L.)

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Authors' contributions:

This work was carried out in collaboration among all authors. Authors JSMF and TIS designed the study, performed statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MLMV and YHL managed bibliographic searches. Author AGSB, TJD transcribed the final version. Authors TJD and JSMF managed the analyzes of the study as well as the work. All authors read and approved the final manuscript.

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ABSTRACT

Beet is one of the vegetables richest in nutrient (bioactive compounds, folic acid and potassium). However, there are few studies on postharvest quality from the crop under irrigation conditions with saline waters, and because of that, the objective of this study was to evaluate effect of saline waters and silicon application in the preharvest on physicochemical quality of the beet. Two experiments were conducted with the objective of evaluating two forms of silicon application: via foliar (experiment 1) and via soil (experiment 2) about its influence in mitigating salt stress. In both experiments was adopted a randomized design with blocks in a 5 x 5 factorial, referring to five levels of electrical conductivity of the irrigation water (ECw): (0.5, 1.3, 3.25, 5.2 and 6.0 dS m^{-1}) five doses of silicon (0.00; 2.64; 9.08; 15.52 and 18.16 mL L^{-1}), they were combined according to the

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experimental matrix Central composite of Box totaling 10 treatments, with four replicates and three plants per plot. After harvesting, 70 days after transplanting, the following characteristics were evaluated: bulb dry mass, pH, titratable acidity (TA), total soluble solids (TSS), TSS/TA ratio and ash. There was a significant effect for the salinity x silicon (Si) interaction applied via soil to the dry matter mass and titratable acidity. The electrical conductivities of irrigation water (ECw) and Si doses via leaf and soil influenced significantly for analyzed variables, except pH, total soluble solids, TSS/TA ratio, ash and titratable acidity, which were not influenced by ECw and nor by the doses of Si via soil and foliage. Irrigation with water of 6.0 dS m^{-1} promotes better quality beet tuber. The fertilization on preharvest with silicon via soil or foliage improved postharvest quality of beet.

Keywords: Beta vulgaris L.; potassium silicate; salt stress.

1. INTRODUCTION

In recent years soil salinization has been a major agricultural concerns, especially in arid and semi-arid regions [1], since in these regions besides the low rainfall and rainfall irregularity, there are still low-quality of water available for irrigation, then farmers use saline water [2], as in the case of producers of vegetables, especially beets.

Although salinity negatively interfere with the growth and development of crops, studies show that the salinity promotes higher quality postharvest of fruits and vegetables, as an example [3], working with watermelon they verified that the increase in the electrical conductivity of the irrigation water (ECw) from 2.77 to 4.91 dS m^{-1} increased the soluble solids content. In cucumber, [4] also found soluble solids content and titratable acidity increased. The same was observed in tomato crops, where [5] found that use of water with salinity from 2.0 to 3.5 dS m^{-1} increases the quality of tomato by increasing the TSS/TA ratio.

On the other hand, despite the increased quality of fruits and vegetables with the use of irrigation with saline water, crop productivity is reduced under salinity conditions. Restrictions on growth are observed due to the interaction of salts with nutrients in the soil, promoting imbalances in the plant nourishment [6,7]. Thus, the accumulation of ions in tissues for long periods can cause injury and death of the plant [8].

One of the strategies to mitigate the salt deleterious effects is the application of substances that mitigate these effects, one of them is silicon [9,10,11,12,13]. Although considered a non-essential element, silicon is a beneficial element, which has the ability to reduce the impact of stressor agents [14]. Studies evidence that the supply of silicon increases crops growth, since this element indirectly acts on some photosynthetic and biochemical aspects, especially in plants under some sort of stress [15,16,17]. Furthermore, the increase in postharvest quality of vegetables with silicon application has been verified, such as lettuce [18] and strawberry [19].

Due to the scarcity in studies vising the effect of irrigation with saline water on postharvest quality of beet tuber, this study aimed to evaluate the effect of saline water and silicon application on physicochemical quality of beet.

2. MATERIALS AND METHODS

2.1 Experimental Location

Two experiments were conducted in a greenhouse located in the Fruit sector belonging to the Federal University of Paraíba, municipality of Areia-PB, Brazil, located in the geographical coordinates 6°51'47" and 7°02'04" South latitude and West longitude 35°34'13 "and 35°48'28" of the Greenwich meridian.

2.2 Experimental Design

These experiments were conducted in order to assess two types of silicon application which were via foliar (experiment 1) and via soil (experiment 2) and their influence as a possible salt stress attenuating. Experiment 1 was conducted from August to October 2017 and experiment 2 from January to March 2018. In the experiments were adopted the experimental design with randomized blocks of factorial 5 x 5 combined according to the experimental matrix Central Compound of Box [20], referring to the electrical conductivity of irrigation water (ECw) and silicon doses (Si) with minimum values (- α) and maximum (α), respectively 0.5 to 6.0 dS m^{-1} and from 0.00 to 18.16 mL L^{-1}, totaling nine treatments, with four replicates and three plants per portion.

Beet seedlings cv. Wonder were grown in trays and planted in pots of 22 cm diameter, 16 cm in bottom diameter and 18 cm high, with a volumetric capacity of 8 dm 3, and circular holes of 1 cm diameter on its bottom face, with purpose of allowing better root aeration and percolation of excess water.

The pots were filled with horizon soil A, collected at the depth of 0-20 cm, classified as Planossolo Háplico Eutrófico êndico/Alfisol [21], the physicochemical characteristics (Table 1) were analyzed according to the methodology of [21], respectively. The soil was air dried previously and properly homogenized, and placed in vessels accommodated previously screened (tulle fabric) and 200 g of crushed rock to prevent soil output by the vessels inferior orifices.

The plants were irrigated daily, at the beginning raising the soil moisture around 80% of the field capacity (CC). The different ECw were obtained using the NaCl, $CaCl_2.2H_2O$ e $MgCl_2.6H_2O$ salts, in the proportion of 7: 2: 1 according to the characteristics presented in Table 2. Irrigation with the water sources of different salinities was started 10 days after the emergence. In the first DAE, the slide was calculated by the equation proposed by [22]. The total required irrigation (ITN), in mm, was calculated by the equation of [23], considering 100% efficiency of irrigation application.

Table 1. Physicochemical characteristics of the soil used in the experiment

Chemicals attributes		**Physicals attributes**	
pH	6.26	Ds	1.38
P (mg dm^{-3})	11.35	Pd	2.67
K^+ (mg dm^{-3})	40	Tp	0.48
Na^+ (cmol dm^{-3})	0.22	CC	78
H+Al (cmol dm^{-3})	1.82	PMP (g g^{-1})	43
Al^{+3} (cmol dm^{-3})	0	Sand (g kg^{-1})	756.9
Ca^{+2} (cmol dm^{-3})	3	Silt (g kg^{-1})	59.1
Mg (cmol dm^{-3})	1.9	Clay (g kg^{-1})	184
BS (cmol dm^{-3})	5.22	-	-
CEC (cmol dm^{-3})	7.03	-	-
V (%)	74.34	-	-
M (%)	0	-	-
OM (g Kg^{-1})	17.53	Textural classification	Sandy franc

*Base Sum (BS) = (Na^++K^++Ca^{2+} + Mg^{2+}); CEC = Cation Exchange Capacity; EC = BS + (H^+ + Al^{3+}); V = (100 x SB/CTC); OM = organic matter. Ds = density of the soil; Pd = particle density; Tp = total porosity; (1- (Ds / Dp) * 100) Ucc =volumetric humidity level of field capacity - 0.033 MPa; Upmp = humidity level of the permanent wilting point - 1.5 MPa*

Table 2. Chemical characteristics of the waters used in the experiment

Attributes	**Electric conductivity (dS m^{-1})**				
	0.50	1.30	3.25	5.20	6.00
	Values				
pH	7.00	7.50	7.40	7.30	7.40
$SO4^{-2}$	3.22	3.70	3.67	3.35	3.90
Mg^{2+}	1.33	1.78	1.93	2.03	2.98
Na^+	1.70	5.92	12.57	20.5	24.20
K^+	0.20	0.21	0.20	0.20	0.21
Ca^{2+}	0.73	1.58	1.78	1.88	2.53
CO_3^{-2}	0.00	0.00	0.00	0.00	0.00
HCO_3-$^-$	2.75	3.50	4.00	4.25	4.25
Cl^-	3.40	10.90	30.40	48.90	58.15
SAR (mmol L^{-1}) $^{0.5}$	1.28	1.87	2.60	3.23	2.96
Classification	*C2S1*	*C3S3*	*C4S4*	*C4S4*	*C4S4*

EC= electrical conductivity at 25 °C; SAR = sodium adsorption ratio [$Na^+/(Ca^{2+}+Mg^{2+}/2)^{1/2}$]; CO_3^{2-} = Absent. Water classification acording [24]

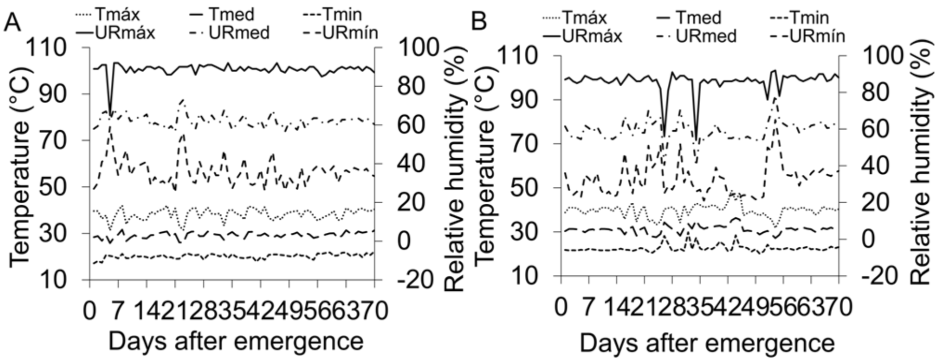

Fig. 1. Graphical representation of the relative air humidity and temperature in the experiments conduction period, experiment 1 (A) and experiment 2 (A)

(Air maximum temperatures (Tmax), mean (Tmeas) and minimum (Tmin) in °C; maximum relative humidity of the air (URmáx), mean (URmed) and minimum (URmin) in%)

Silicon was applied as liquid potassium silicate (K_2SiO_3) with 12% Si and 15% K_2O. In the first experiment, Si doses were applied through a hand sprayer and in the second experiment the application was carried out directly in the vessels. In these experiments, there was compensation of K_2O via foliar and via soil in the applications used in beets with the purpose of supplying the same amount of potassium for all plants. The silicon application was done weekly, totaling 7 applications during the beet cycle. The doses of (Si) were diluted in 1.2 L of distilled water and 50 ml of this solution was applied to each plant according to the each via of application.

During the experiments conduction, the atmospheric data (Fig. 1) were recorded daily with the HT-600 Instruthermr® digital the rmohygrometer installed inside the experimental area, at plants height. In both experiments, mean temperature and weather values were close to the ideal range (25°C) during the crop cycle, according to [25].

Cover and fertilization of the plantation were done with 40, 180 and 90 kg ha^{-1} of NPK, respectively, with urea, simple superphosphate, and potassium chloride according to the chemical analysis of the soil and fertilization recommendation for the state of Pernambuco, Brazil [26]. Phytosanitary controls of pests and weeds were carried out during the experiment.

2.3 Determination of Physico-chemical Parameters

After harvesting, 70 days after transplanting, the following characteristics were evaluated: bulb dry mass, pH, titratable acidity (TA), total soluble solids (TSS), TSS/TA ratio and ash.

Dry matter mass was obtained after weighing the bulb in an analytical balance, after drying in oven at 65ºC; pH was measured with bench PH meter; the titratable acidity (g pulp 100 g^{-1} citric acid), by titration of the juice with NaOH a 0,1 M solution; Soluble solids content, determined with digital refractometer; the TSS/TA ratio was through division; for ash determination, the methodology of the [27] was adopted, from the incineration in muffle for 6 hours at a temperature of 550°C.

2.4 Data Analysis

The obtained data were submitted to analysis of variance and polynomial regression, and the mixed model (MIXED) was used for the repeated evaluations in time using the statistical software SAS® University [28].

3. RESULTS AND DISCUSSION

There was a significant effect for the salinity x silicon (Si) interaction applied via soil to the dry matter mass and titratable acidity. The electrical conductivities of irrigation water (ECw) and Si doses via leaf and soil influenced significantly for analyzed variables, except pH, total soluble solids, TSS/TA ratio, ash and titratable acidity, which were not influenced by ECw and nor by the doses of Si via soil and foliage.

The increase of salinity in the irrigation water promoted a linear increase in the beet bulb dry matter mass, presenting maximum values in the irrigated plants with water of 5.2 and 6.0 dS m^{-1}, obtaining up to 18 g. Plants irrigated with the salt water of 1.3 dS m^{-1} presented the lowest dry matter mass of the bulb, obtaining 14.2 g, a reduction of 21.11% in plants irrigated with water of 0.5 dS m^{-1} compared to those under 5.2 and 6.0 dS m^{-1} (Fig. 2A).

The dry matter mass presented decrease with the increase of the water salinity and with silicon doses via soil, the highest values were obtained when these plants were irrigated with water of low salinity (0.5 dS m^{-1}) and without application of silicon (0 ml L^{-1}) was obtained 23 g of dry matter mass of the bulb. By increasing the values of ECw and the silicon doses there was a reduction until 5.2 dS m^{-1} and 9.08 ml L^{-1}, in this order, with later addition until a dose of 18.16 ml L^{-1} of silicon (Fig. 2B).

The pH of the beet pulp adjusted itself to the quadratic regression model, with an increase due to the increase in Si doses via foliage; the pH values were raised to 5.94 relating to estimated optimal dose of 9.08 ml L^{-1} (Fig. 3). Si doses above 9.08 mL^{-1} have reduced the beet pulp pH to the dose of 15.52 mL L^{-1} with further increase up to 18.16 mL L^{-1}. The values found in this study are considered low. pH works as an indication of the vegetable flavor, having relation inverse to the acidity [29].

These results corroborate to those obtained by Korkmaz et al. (2017) in tomato, they found that the increase in ECw from 0 to 4.4 dS m^{-1} promoted an increase of the fruit pulp pH. [5] also observed that which pH of the tomato pulp increased with salinity increasing in irrigation water, with a maximum value of 4.8 in plants under 5.0 dS m^{-1}.

It was observed that the increase in ECw promoted increase in titratable acidity of beet pulp, then plants subjected to the highest ECw (6.0 dS m^{-1}) had the highest titratable acidity (0.23 g citric acid) and plants irrigated with water of lower ECw (0.5 dS m^{-1}) had the lowest titratable acidity (0.17 g citric acid), 29.16% reduction comparatively (Fig. 4A).

As increased salt concentration in the irrigation water has been found that the titratable acidity of 0.08 g of citric acid under 0.5 dS m^{-1} increased 0.16 g of citric acid in the beet pulp irrigated with water of highest salinity, increasing up to 50%. [30] also found that the titratable acidity on melon had increased with the increase of the salinity of irrigation water, which observed increase of 0.107% citric acid ECw 0.49 and 1.75 dS m^{-1}, however, the authors also noted that from these salinity the titratable acidity reduced 4.7% when had water salinity increased until 2.4 dS m-1.

On the other hand, it was verified that the increase in Si doses reduced the titratable acidity of the beet pulp up to the Si dose of 9.08 mL L^{-1} with subsequent increase until reaching the maximum dose (18.16 mL L^{-1}), yielding 0.10 g of acid with the this application (Fig. 4B). This behavior was also verified by [18] in lettuce, which observed that the treatment with 28 mg L^{-1} of silicon, obtained 140 mg of citric acid 100 g^{-1} of fresh matter, being greater than in the plants of the control that presented average values of 114 mg of citric acid 100 g^{-1}.

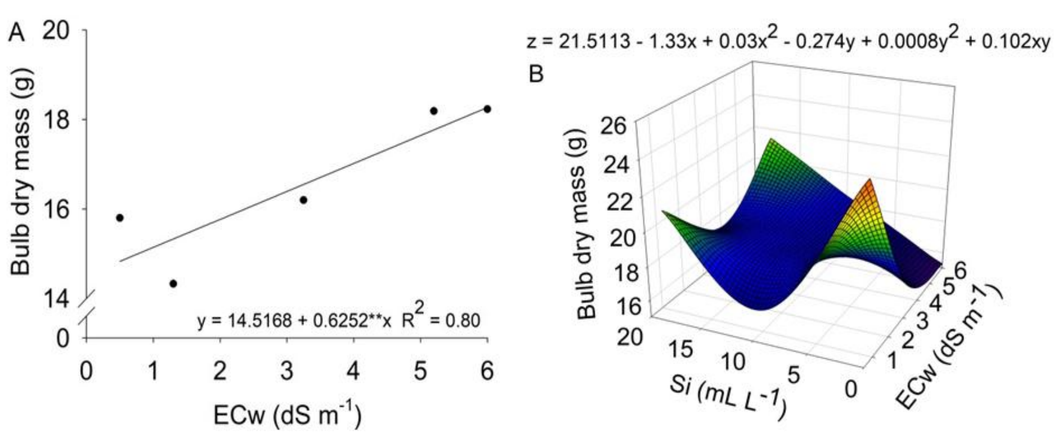

Fig. 2. Electrical conductivity effect of the irrigation water (A) and the electric conductivity of silicon doses applied to the soil and in the irrigation water (B) in the dry matter of beet bulb

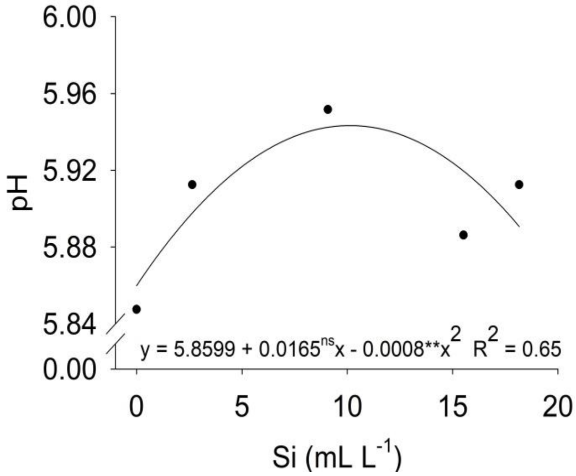

Fig. 3. Effect of silicon doses via foliage in the pH of beet pulp

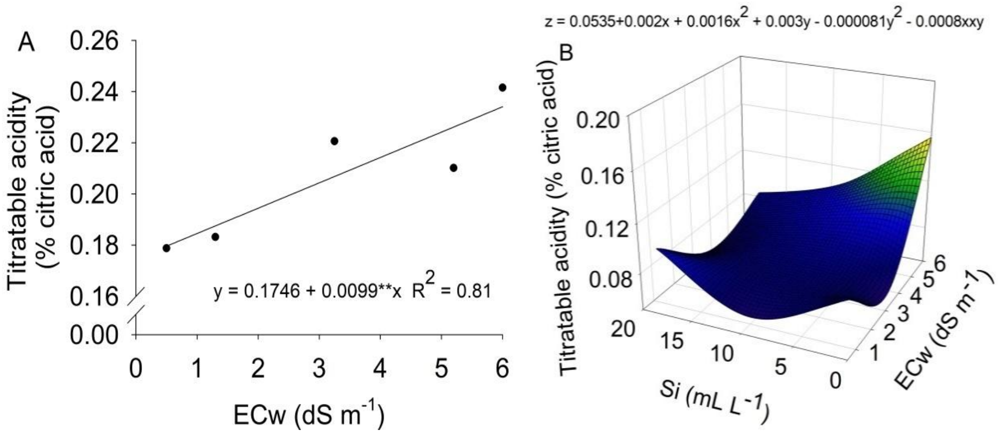

Fig. 4. Electrical conductivity effect of the irrigation water and doses of silicon applied via foliage (A) and via soil (B) in the titratable acidity of beet

The increase in the titratable acidity of the beet pulp in function of the silicon doses corroborates the data obtained by [19] in strawberry, in which the highest values for titratable acidity were with the application of Si via foliage, in which 1.19 mg of citric acid 100 g^{-1} was obtained with the application of 69 mg kg^{-1} of Si, and via soil the highest value was 1.13 mg of citric acid 100 g^{-1}, with the application of 97.5 mg kg^{-1} of Si.

There was an increase in the soluble solids contents of the pulp when the beet plants were irrigated with saline water and silicon application, in both Experiment I (Fig. 5A) and Experiment II (Fig. 5B). In the experiment I, data were adjusted to the linear model increasing, and then the increase in the ECw promoted an increase in the soluble solids content, in which the maximum value of 15.7º Brix was obtained in the plants irrigated with water of 6.00 dS m^{-1} (Fig. 5A). In the experiment II, data were adjusted to the quadratic regression model, where the maximum value in the soluble solids content was obtained in the plants that have received 9.08 mL L^{-1} of silicon, obtaining 14.3º Brix (Fig. 5B).

Similar results were observed by [3] in melon, when they verified that the increase in salinity in the irrigation water from 2.77 to 4.91 dS m^{-1} promoted an increase in the soluble solids content of the 'Shadow' cultivar, increasing the soluble solids values from 3.58 to 5.08%, respectively. Medeiros, et al. [4] also verified that saline increase in irrigation water increases the content of soluble solids in cucumber. The

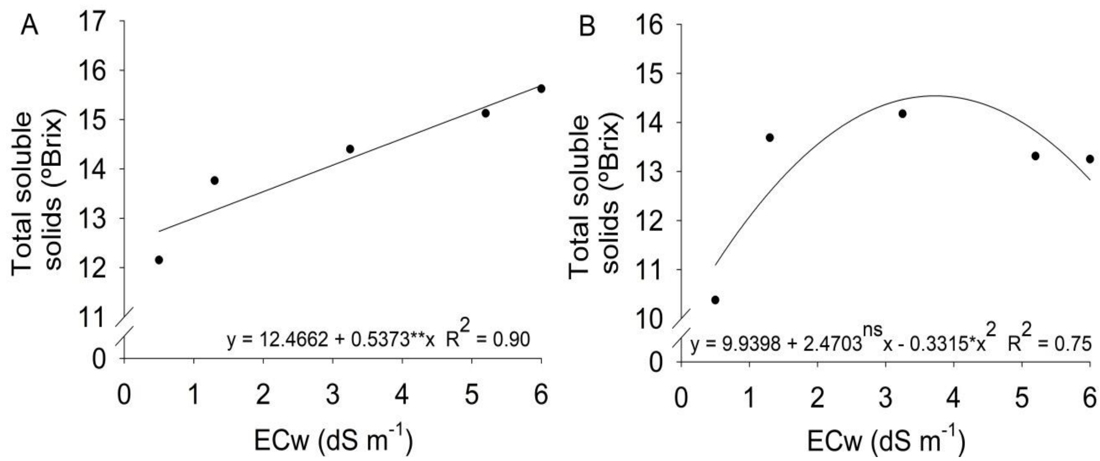

Fig. 5. Electrical conductivity effect irrigation water (A) and application of silicon via soil (B) on soluble solids contents of beet pulp

increase in soluble solids content in the beet pulp with increase of water salinity may have been due to the increase in the concentration of photoassimilates (solutes), since the increase in the soluble solids is mainly due to the deleterious effects of the salts that reduce the bulbs average weight, but they increase soluble solids [31].

5. CONCLUSION

Using water with an electrical conductivity of 6.0 dS m^{-1} promotes better tuber beet quality;

The fertilizations on preharvest with silicon, applied via soil or foliage, improved the postharvest quality of the beet.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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