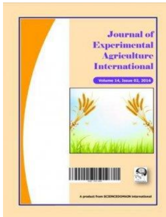

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Application of Silicon to Alleviate Irrigation Water Salinity in Melon Growth

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Authors' contributions

This work was carried out in collaboration with all authors. The authors FALG, JSN and RTF prepared the study, participated in all the steps of conducting and writing the manuscript. The author RHCRA consists of the research supervisor, showing the alternatives of conducting and evaluating the data. The authors MSS, ASS and AEMMT were of paramount importance in conducting and evaluating the experiment, process of typing the data for later statistical analysis. Author CJAO managed the decisived in the corrections phase, showing alternatives to enrich the information work. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study aimed to assess the alleviating effect of silicon in salinity on melon growth.
Study Design: The experimental design was in randomised blocks, corresponding to the with four salt levels and three doses of silicon.
Place and Duration of Study: The experiment was conducted in a protected environment at Center of Sciences and Agri-Food Technology of the Federal University of Campina Grande, Campus of Pombal, Paraiba, Brazil, between October and December 2017.

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Methodology: The experiment was randomised blocks, in a 4x3 factorial scheme, with four salt levels (0.3, 1.3, 2.3 and 3.3 dS m^{-1}) and three doses of silicon (Sí1) = 0; (Sí2) = 3.2; (Sí3) = 6.4 $g.L^{-1}$ per plant, applied via soil with four repetitions of 12 plants. As vegetable material the 'Hales Best Jumbo' melon hybrid of the Cantaloupensis group was used.
Results: Salinity severely affected the leaf area, shoot dry weight and total weight and the Dickson quality index. On the other hand, silicon had a significant effect on leaf number, plant height, stem diameter, root length, number of flowers, and number of flower buds, root dry weight and extravasation of electrolytes.
Conclusion: The application of silicon alleviated the salinity effect favoring melon growth, especially when the dose of 3.2 g. L^{-1} was applied.

Keywords: Cucumis melo L.; salinity stress; alleviation.

1. INTRODUCTION

The melon plant (*Cucumis melo* L.) is one of the main species grown in the Northeast region of Brazil with a great importance for the producers and for the economy in that region. The edaphoclimatic conditions with high temperatures, low relative humidity and long period of luminosity are characteristics that make possible the exploration of this culture [1]. However, the Northeastern semi-arid region presents soils and irrigation water with high levels of salts, which promote serious damages to culture growth and productivity.

The most damaging effects of salinity are seen on seed germination, reduced osmotic potential, increased ionic toxicity and imbalance in water and nutrient absorption, leading to a generalised reduction in plant growth and resulting in severe damages to the agricultural activity [2,3]. Thus, it is necessary to adopt a management strategy that alleviates the effect of salts, with the silicate fertilisation being a promising alternative.

Silicon is an element that alleviates the effect of abiotic stresses, acting mainly as a function of the accumulation in the cell walls of roots, stems and leaves [4]. The soluble Si has an active role that potentiates plant defence mechanisms with the increase in the production of phenolic compounds, in the levels of some classes of phytoalexins and in the activation of some genes that encode PR proteins [5]. According to Ma & Yamaji [6], silicon is a nutrient that performs several functions in the plant, in disease control, reduction of effects promoted by abiotic stresses such as salt, water, heavy metal toxicity and nutritional imbalance.

In this context, the objective of this work was to assess the silicon's ability to alleviate the effects of salinity on melon seedlings (*Cucumis melo* L).

2. MATERIALS AND METHODS

2.1 Location of the Experiment

The experiment was conducted in a protected environment at Center of Sciences and Agri-Food Technology of the Federal University of Campina Grande, Campus of Pombal, Paraiba, Brazil.

2.2 Description of Treatments

The experimental design was randomised blocks in a 4 × 3 factorial scheme, with four levels of water salinity (ECw= 0.3; 1.3; 2.3; and 3.3 dS m^{-1}); and three doses of silicon: (Sí1) = 0; (Sí2) = 3.2; (Sí3) = 6.4 $g.L^{-1}$ per plant, applied via soil, and four repetitions of 12 plants. Saline waters were prepared using urban water and sodium chloride (NaCl), calcium chloride dehydrate ($CaCl_2 2H_2O$) and magnesium chloride hexahydrate ($MgCl_2 6H_2O$) in the proportion of 7: 2: 1, which is equivalent to the proportion of salts predominant in the main sources of water available for irrigation in the Northeast Region of Brazil, calculated based on the relation between EC and salt concentration: mmolc L^{-1} = EC × 10 [7].

As the source of Silicon, Quimifol was used, composed of 15% silicon and 10% potassium totally soluble in water with doses of Silicon (Sí2) = 0; (Si2) = 3.2; (Sí3) = 6.4 $g.L^{-1}$ which was applied per treatment. The potassium doses were compensated with the potassium chloride fertiliser with the following proportions: (Sí1) = 8.28 g KCl; (Sí2) = 4.14 g de KCl e (Sí3) = 0, applied in each treatment.

2.3 Plant Material and Experience Management

The seedlings were produced in 200-cell expanded polystyrene trays using Baseplant®

substrate and two seeds per cell of the 'Hales Best Jumbo' melon hybrid from Cantaloupensis Group were sown. Seven days after the establishment of the seedlings, they were transplanted to polystyrene bags with a capacity of 1 Kg/dm^3, filled with the soil classified as Neossolo Flúvico, with an average granulometric composition of 795 g kg^{-1} of sand, 117 g kg^{-1} of silt and 88 g kg^{-1} of clay, and the following chemical attributes in the 0-20 cm depth layer: pH (H_2O) 8.2; OM, 0 g dm^{-3}; P, 1.494 $mg.dm^{-3}$; H+Al, 0.0 $cmolc.dm^{-3}$; K, 0.51 $cmolc.dm^{-3}$; Ca, 7.8 $cmolc.dm^{-3}$; Mg, 2.7 $cmolc.dm^{-3}$; SB, 11.2 $cmolc.dm^{-3}$; CTC 11.2 $cmolc.dm^{-3}$; and 100% base saturation according to the Brazilian Soil Classification System [8].

Irrigation with saline water initiated 5 days after transplanting the seedlings and the frequency of the irrigation was twice a day. The volume of water applied was established according to the average evapotranspiration of the test sample (0.3 dS m^{-1}), by calculating the volume of water applied by equation 1:

$$Va = Pcc - Pa / n \quad (1)$$

Where: Va = volume applied; Pcc = container weight in maximum water holding capacity; Pa = average weight of the containers in the current condition; n = number of containers.

The application of silicon was divided in four instances, considering the day of transplanting, at 15, 25 and 35 days after transplanting (DAT) via fertirrigation by diluting the silicon in 0.3 dS m^{-1} EC water for all treatments.

2.4 Variables Assessed

After 40 DAT, the growth evaluations were performed, and the following variables were assessed:

- Height of plants: obtained from the measurement of the length of the main branch starting from the base to the apex of the plant by using a millimeter ruler, with the results expressed in cm;
- Number of leaves: obtained by counting the number of fully mature leaves;
- Stem diameter: calculated with a digital caliper and the results are expressed in mm;
- Root length: obtained by measuring the length of the root with the aid of millimeter ruler, the results being expressed in cm;
- Number of flowers: calculated by counting the number of flowers fully open;
- Number of flower buds: calculated by counting the number of flower buds;
- Leaf area: obtained by measuring the width of each leaf in the plant, the values obtained were summed and, with the results of the final width, the final value was determined with a regression equation observed by Nascimento [9], obtained through the formula:

$$AF = 108^* LFF - 518$$

Where: AF = total leaf area of the plant and LFF = final leaf width.

- Shoot dry weight, root dry weight and total weight: result obtained by separating the parts of the plant from the plant root collar which has been packaged separately in bags of kraft paper. The samples were then dried in an air-forced oven and maintained at 65°C until constant weight was reached. Total dry weight was obtained by summing the values of the root and shoot dry weight. The results were expressed in grams per $plant^{-1}$;
- Dickson quality index: determined according to equation (2), which relates the total dry weight (TDW), height (HP), root collar diameter (DC), shoot dry weight (MSPA) and root dry weight (MSR) [10].

$$IQD=TDW/ (HP/DC)/ (MSPA/MSR) \quad (2)$$

- Relative water content: to determine this variable, a large and vigorous leaf was collected and weighed in an analytical balance and then conditioned inside a plastic bag, with a solution of 100 ml of distilled water and left to stand for 24 hours. Subsequently, the leaf was weighed after stand and the relative water content was obtained by calculating the difference between the two weightings values.
- Extravasation of electrolytes: consisted of the removal of eight discs from a completely mature leaf; the discs were immersed in 50 ml of distilled water, and then the initial readings were conducted with a digital sensor. The samples were then placed in an air-forced oven at 90° C, after 4 hours they were removed and further readings were gathered. The result was obtained by calculating the difference between the values of the final and initial readings in Us.

2.5 Statistical Analysis

The variables were subjected to analysis of variance by F test (.01 and .05 probability levels) and, in cases of significant effect, linear and quadratic polynomial regressions were applied, using the statistical program SISVAR [11].

3. RESULTS AND DISCUSSION

The relative water content in melon seedlings was not influenced by the applied treatments. For the variables of leaf number, plant height, root collar diameter and root length, the quadratic effect was verified as a function of the treatments applied, and the salinity effect was alleviated by the silicon doses up to 3.2 $g.L^{-1}$ (Fig. 1).

The number of leaves showed the highest values at dose 0 to 1.7 dS m^{-1} maximum salinity level (Fig. 1A). 3.2 and 6.4 $g.L^{-1}$ doses presented different effects: 3.2 dose alleviated the effect of salinity to 0.7 dS m^{-1} saline level. On the other hand, the 6.4 $g.L^{-1}$ dose of silicon did not promote an alleviating effect due to the salinities of the irrigation water.

The effect of Si on growth is still very controversial, due to positive and negative responses are found in the literature on different plant species. Zanão Júnior [12] in wheat (*Triticum aestivum* L.), Rezende [13] in physalis (*Physalis peruviana* L.). On the other hand, Nascimento [14] observed an increase in rice plants growth (*Oryza saiva* L.) and Lima [15] in maize (*Zea mays* L.) due to of silicate fertilisation.

Plant height and root collar diameter were influenced by the factors studied, showing an alleviating effect of salinity due to silicon doses (Fig. 1B and 1C). It was observed that doses presented different behaviours, where the dose that most alleviated the effect of saline stress was the 3.2 $g.L^{-1}$ one, with the largest increments until 3.3; 2.2 dS m^{-1} saline levels, respectively.

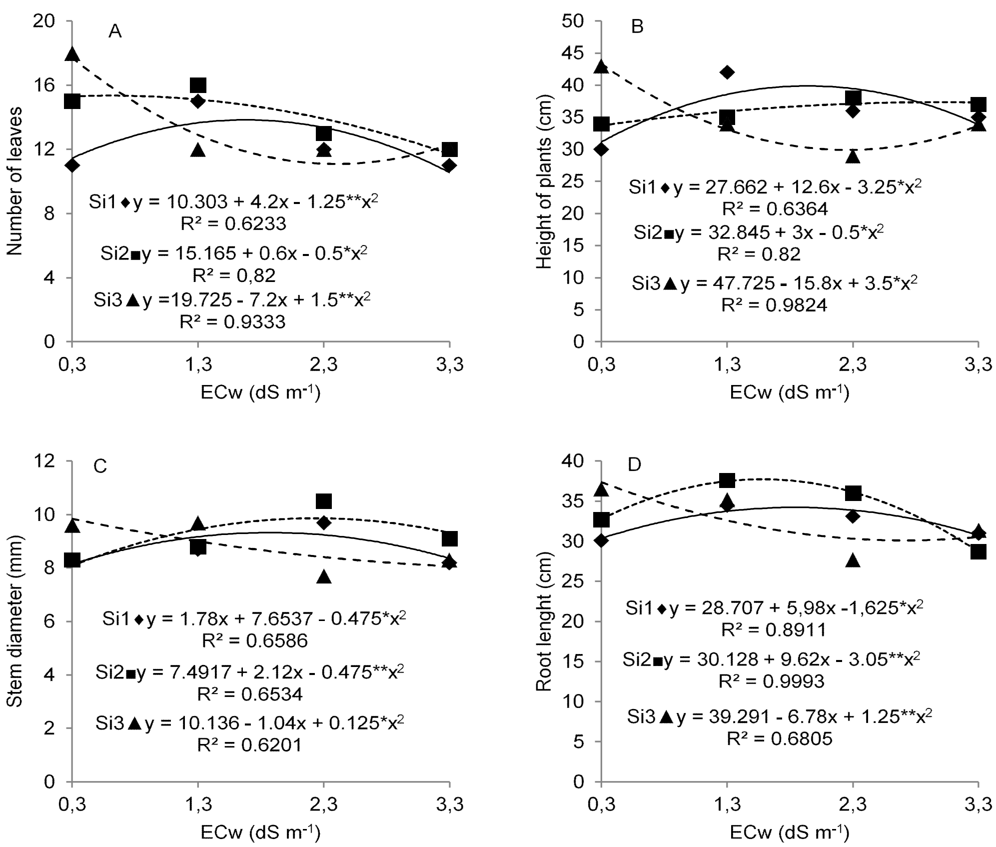

Fig. 1. Number of leaves (A), height of plants (B), stem diameter (C) and root length (D), of *Cucumis melo* L., as a function of different salinities of irrigation water and silicon doses
*** P<0.01; * P<0.05*

On the other hand, the plants produced with the application of 0 and 6.4 g.L^{-1} doses presented the highest values in 1.9 and 0 dS m^{-1} saline concentrations. This effect promoted by the 3.2 dose could have occurred due to a greater lignification of the tissues. Silicon performs several mechanisms in the plant when subjected to saline stress, promoting nutrient homeostasis, osmotic adjustment, regulation and synthesis of compatible compounds, stimulation of enzymes and expression of resistance genes [16].

Melon root length showed similar results for 0 and 3.2 g.L^{-1} of Si doses, with the highest values in 1.8 and 1.6 dS m^{-1} salinities, respectively (Fig. 1D). On the other hand, the 6.4 dose did not show alleviating effect on salts contained in irrigation water, and this effect may be caused by the accumulation of silicon in the tissues. This effect can be attributed to the higher accumulation of Si occurring in the shoot. When accumulating in leaves, Si promotes a protective barrier against water loss through evapotranspiration, promoting little effect on root growth [17].

For the number of flowers, the quadratic effect for the silicon doses is verified due to the irrigation water salinity (Fig. 2A). 3.2 and 6.4 g.L^{-1} doses of Si promoted the highest emergence of fully formed flowers at 2, 1.7 and 1.6 dS m^{-1} salt levels, respectively. It is observed that the highest number of flowers in the 3.2 g.L^{-1} dose, being the limit tolerated, since the increase of the dose promoted a decrease in the number of flowers. Silicon promotes a greater production of flowers, due to the higher nutritional balance [18].

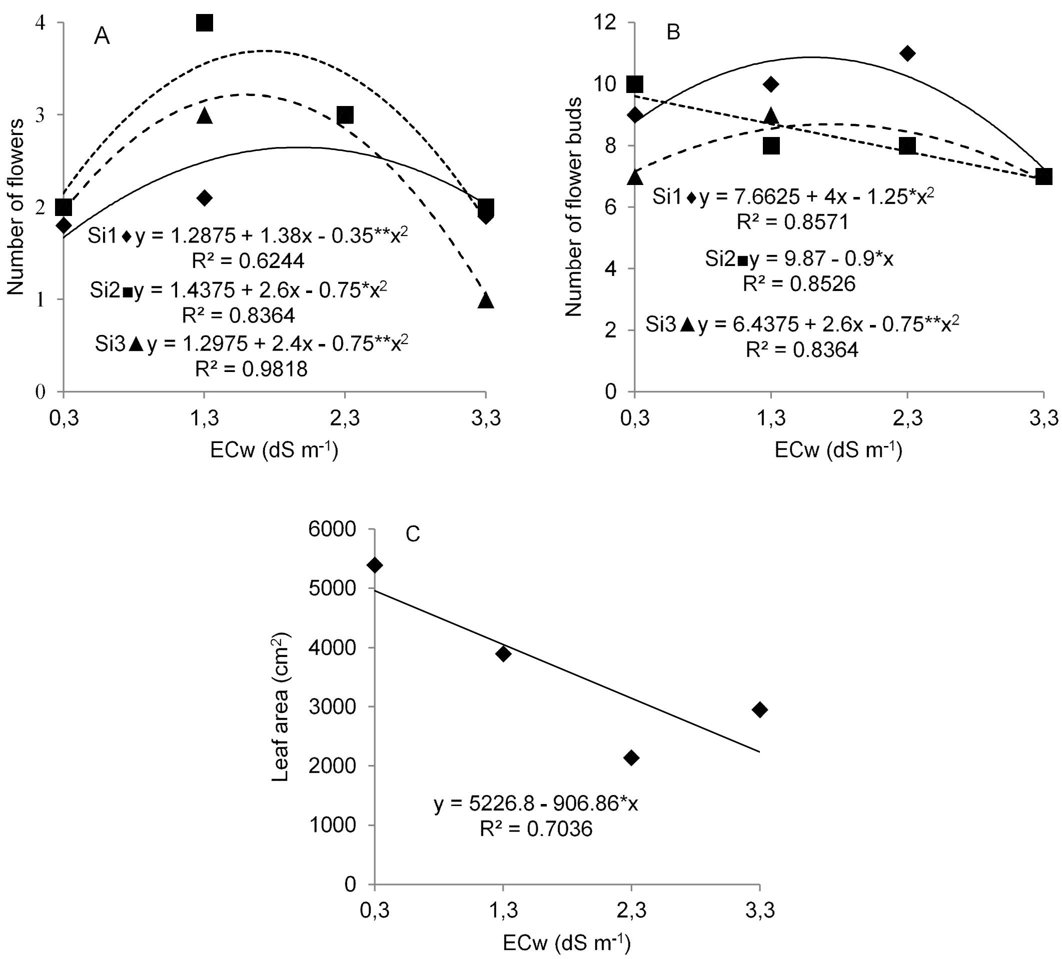

Fig. 2. Number of flowers (A), number of flower buds (B) and leaf area (C) of *Cucumis melo* L., as a function of different salinities of irrigation water and silicon doses

*** P<0.01; * P<0.05*

On the other hand, the number of floral buds presented a different behavior compared to the number of flowers where 0 and 6.4 g.L^{-1} doses presented a quadratic effect while 3.2 g.L^{-1} dose of Si presented a linear decreasing effect due to salinity increase (Fig. 2B). It is observed that the highest number of buds was obtained in the plants that received the dose 0, showing that Si did not promote increase for this variable. Increasing the applied doses of Si does not guarantee the amount applied to be absorbed by the plant. There may also be a low transporter activity between the root and the xylem [19], causing the absorbed Si not to be transported by the plant.

The leaf area was influenced only by salinity, obtaining severe losses when the plants were submitted to higher salinity, occurring a reduction of 5,532 cm² in the 0.3 dS m^{-1} level to 2,811 cm² in the 3.3 dS m^{-1} level, promoting a reduction of 2,721 cm², in contrast to the values obtained in water with lower and higher electrical conductivity (Fig. 2C). This effect can be attributed to the high level of salinity, because seedlings present the symptoms in the growth phase, negatively affecting the process of photosynthesis of the vegetable. Salinity promotes several serious deleterious effects on the plant, causing oxidative stress and resulting in damage to the photosynthetic apparatus and pigments involved [20].

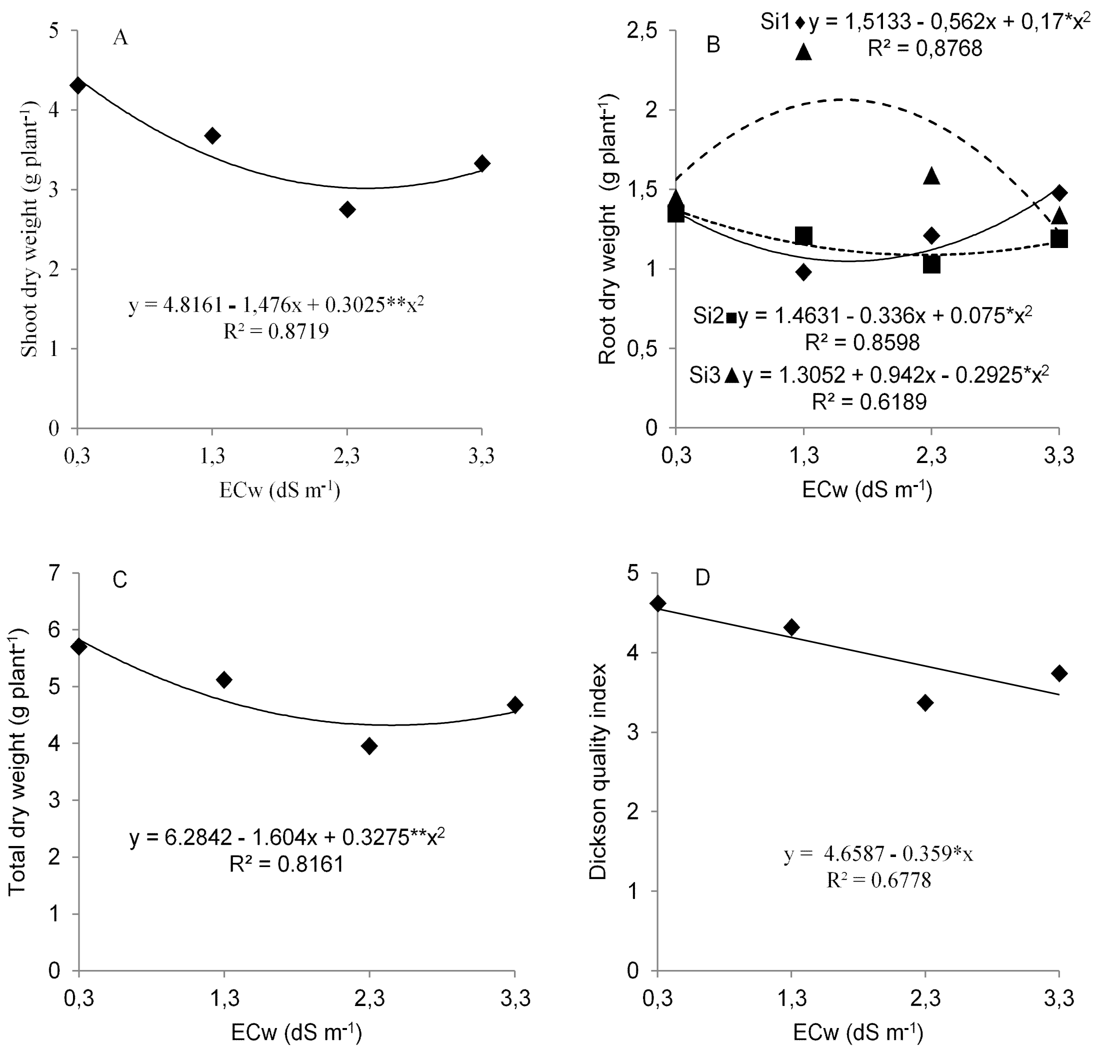

Fig. 3. Shoot dry weight (A), root dry weight (B), total dry weight (C) and Dickson quality index (D) of *Cucumis melo* L., as a function of different salinities of irrigation water and silicon doses
*** P<0.01; * P<0.05*

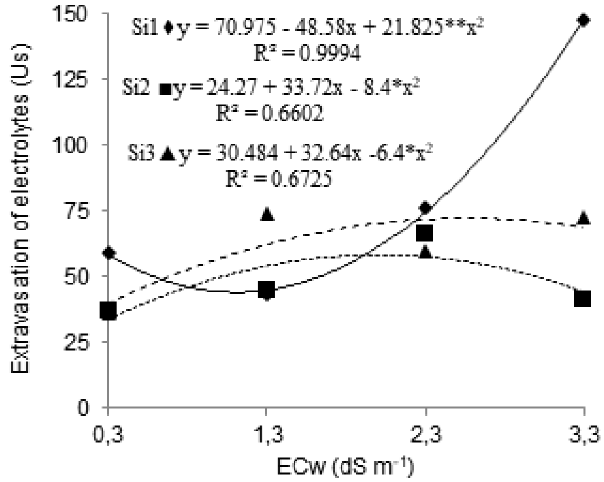

Fig. 4. Extravasation of electrolytes in *Cucumis melo* L., as a function of different salinities of irrigation water and silicon doses
*** P<0.01; * P<0.05*

For the variables of shoot dry weight and total dry weight, they were influenced only by the saline levels, and a quadratic effect was observed due to the irrigation water salinity, being the largest increases in the biomass accumulation occurred in the 0.3 dS m^{-1} salt level (Figs. 3A and 3C). This reduction in the accumulation of dry weight of the plants may be related to the reduction of the photosynthetic capacity of the plants, due to ionic interactions promoted by the excess of sodium salts [21]. This promotes a reduction in the production and accumulation of photo assimilates, as well as an increase in energy expenditure in the plant due to the reduction of osmotic potential, which promotes the reduction of water availability for plant growth [19].

For the root dry weight, it is observed that the three doses of Si were adjusted quadratically to the saline levels, with the greatest accumulation of biomass in the plants produced with the 6.4 g.L^{-1} dose of Si and submitted to the 1.6 dS m^{-1} salinity (Fig. 3B). This alleviating effect may be caused by improvements in the nutritional balance of the plant, since salinity tends to promote nutritional imbalance. Thus, the application of Si promotes nutritional benefits to the plant by the accumulation in the cell wall of the roots [4], reducing the effect of salt stress and promoting a greater accumulation of biomass.

The Dickson quality index was severely affected by salinity, with values adjusted to a linear decreasing effect with the highest values with 4.6 in the electrical conductivity of 0.3 dS m^{-1}, with a reduction in values reaching 3.5 at 3.3 dS m^{-1} saline level (Fig. 3D). This parameter is indicated as a good indicator of seedlings quality, since the higher the DQI value the more vigorous the seedling will be, due to the relation of greater robustness and weight distribution in the plant [22].

Regarding the extravasation of electrolytes, the doses of Silicon promoted the alleviation of the effects of saline stress, showing that the plants produced at dose 0 of Si were the ones that promoted the largest electrolyte leakage, occurring a release of about 150 Us in the 3.3 dS m^{-1} salinity (Fig. 4). Sousa [23], studied the cell membrane damage in citrus irrigated with saline water and found that the higher release of electrolytes occurs due to the elevation of salinity, indicating that the cell membrane resistance to damages promoted by the saline conditions is related to the stability of the membrane, since when the lower the electrolyte loss the more stable the membrane, a fact that was observed in the doses of 3.2 and 6.4 gL^{-1} Si that reduced these losses, reaching the maximum values of 58 and 72 Us in 2.1 and 2.7 dS m^{-1} saline levels. This alleviating effect may be caused by higher stiffness of the cell wall of the leaf due to silicon accumulation. Si maintains cellular integrity by forming a layer of cuticular silica [24]. When absorbed as monosilic acid (H_4SiO_4), the greatest accumulation of silicon occurs in areas where there is greater transpiration [25], occurring mainly in the leaves, improving the plant architecture and promoting greater stiffness by deposition of Si [26].

4. CONCLUSION

Salinity severely affected the melon growth (*Cucumis melo* L.), reducing the leaf area, the accumulation of biomass in the shoot and total accumulation of biomass and Dickson quality index.

Silicon alleviated the effects of salinity, improving conditions for *C. melo* L. plants growth, especially those receiving the 3.2 g.L^{-1} dose.

The application of silicon promoted a greater stiffness in melon leaves (*C. melo* L.), resulting in a lower release of electrolytes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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