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Fertigated cultivation of mini watermelon subjected to salinity levels and foliar application of silicon

Cultivo fertirrigado de mini melancia submetida à níveis de salinidade e aplicação foliar de silício

Cipriano A. da Luz Neto[1], Everaldo M. da Silva[1], Wéverson L. Fonseca[1]*, Iuri de A. Moreira[1], Kamilla D. Pessoa[1], Marcos A. Feitoza[1]

[1]Department of Agronomy, Universidade Federal do Piauí, Bom Jesus, PI, Brazil.

ABSTRACT - The application of silicon (Si) represents one of the alternatives that can be used to mitigate the deleterious effects caused by salinity on plants in fertigated cultivation. The objective was to evaluate the effect of different levels of water salinity, associated with the use of sodium silicate on the production parameters and nutrient levels in the leaf and stem of mini watermelon in a protected environment. To conduct the experiment, a randomized block design was adopted, in a 6 x 2 factorial scheme, with 4 repetitions, with six levels of irrigation water salinity (1.05; 2.12; 3.26; 4.41; 5.91 and 7.32 dS m^{-1}) and two types of Si application: without Si and in foliar solution. The following parameters were evaluated: plant height, stem diameter, number of leaves, leaf and stem fresh and dry mass; biometric variables and total soluble solids content in the fruits; and nutrient contents in leaves and stem. The use of Si associated with fertigation with different salinity levels promoted a positive response for peel thickness, ºBrix, fresh and dry mass of leaves, and Si accumulation in leaves and stem. Salinity alone promoted an increase in pulp weight, ºBrix of the fruits and potassium content in the stem, besides increasing the manganese content and inhibiting the zinc content in the leaves. There was a significant interaction for the manganese content in the stem, with a positive response in the absence of foliar-applied Si and a negative response in the presence of foliar-applied Si under different levels of salinity.

Keywords: *Citrullus lanatus*. Protected environment. Salt stress. Beneficial element.

RESUMO - A aplicação de silício (Si) representa uma das alternativas que podem ser utilizadas para mitigar os efeitos deletérios às plantas pela salinidade em cultivo fertirrigado. Objetivou-se avaliar o efeito de diferentes níveis de salinidade da água, associado ao uso de silicato de sódio sobre os parâmetros produtivos e os teores de nutrientes na folha e no caule da mini melancia em ambiente protegido. Para condução do experimento adotou-se delineamento em blocos casualizados, em esquema fatorial 6 x 2, com 4 repetições, sendo seis níveis de salinidade da água de irrigação (1,05; 2,12; 3,26; 4,41; 5,91 e 7,32 dS m^{-1}) e dois tipos de aplicações de silício: sem silício e aplicação em solução via foliar. Foram avaliados: a altura das plantas, diâmetro do caule, número de folhas, peso da matéria fresca e seca de folhas e caule; variáveis biométricas e teor de sólidos solúveis totais nos frutos; e teor de nutrientes nas folhas e caule. O uso do silício associado a fertirrigação com diferentes níveis de salinidade proporcionaram resposta positiva para espessura de casca, ºBrix, massa fresca e seca de folhas e, acúmulo de silício nas folhas e caule. A salinidade isolada proporcionou aumento para peso de polpa, ºBrix dos frutos e teor de potássio no caule e, incrementou o teor de manganês e inibiu teor de zinco nas folhas. Houve interação significativa para o teor de manganês no caule, com resposta positiva na ausência de silício foliar e negativa com aplicação foliar de silício sob diferentes níveis de salinidade.

Palavras-chave: *Citrullus lanatus*. Ambiente protegido. Estresse salino. Elemento benéfico.

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***Corresponding author:**
<weversonufpi@gmail.com>

INTRODUCTION

Watermelon (*Citrullus lanatus* (Thunb.) Matsum & Nakai) is moderately tolerant to salinity of irrigation water, i.e., it tolerates electrical conductivity (ECw) of up to 3.0 dS m^{-1}, with no losses in yield (BEZERRA et al., 2017). The effects of salinity stress on watermelon cultivation significantly affect the following variables: main branch length, stem diameter, number of leaves, leaf area, shoot dry mass, root length and dry mass, net CO_2 assimilation, transpiration rates, stomatal conductance and water use efficiency (SOUSA et al., 2016; SILVA JÚNIOR et al., 2017). The mini watermelon cv. Smile is considered moderately sensitive to the effects of salinity (SOUSA et al., 2016).

Fertigation is a fertilization practice in which nutrients are applied in crops in small portions, together with irrigation water (RAJENDRAN; IRENE, 2018; AZAD et al., 2018; WANG et al., 2019). Provided that it is carried out with criteria, it has a series of technical and economic advantages compared to traditional methods of fertilization; due to the greater splitting in nutrient application, it allows soil fertility to be maintained close to the optimal level throughout the crop cycle, enables yield gains and reduces nutrient losses

(SOUSA et al., 2016). However, frequent applications of nutrients via fertigation causes accumulation of salts in the substrate, thus increasing salinity levels.

In this context, one of the alternatives to mitigate the effect of salt stress on plants is the supply of silicon (Si) (ZUSHI; MATSUZOE, 2017; YAGHUBI et al., 2019). Although Si is not considered an essential nutrient for plants, this element is responsible for protecting them from stresses caused by biotic and abiotic factors including water deficit, salinity, metal toxicity, nutritional imbalance, pathogens and insect pests (REYNOLDS et al., 2016; ZUSHI; MATSUZOE, 2017; YAGHUBI et al., 2019; ISLAM et al., 2020). The beneficial effect of Si on plants grown under conditions of abiotic stresses occurs due to improvements in antioxidant systems, contributing to the maintenance of the physical integrity of the membrane, reducing electrolyte leakage (BARRETO et al., 2018). Si protects the photosynthetic apparatus (VACULÍKOVÁ et al., 2014) and increases the absorption of nutrients (MANTOVANI; PRADO; PIVETTA, 2018), making plants more tolerant to the deleterious effects caused by stress.

The beneficial effects of Si under salt stress have already been reported in tomato yield (ZUSHI; MATSUZOE, 2017) and in the production and quality of strawberry fruits (YAGHUBI et al., 2019). In view of the above, the objective of this study was to evaluate the effect of different levels of water salinity, associated with the use of Si, on the production parameters and nutrient contents in the leaves and stem of mini watermelon in a protected environment.

MATERIAL AND METHODS

The experiment was conducted from August to November 2019, at the Federal University of Piauí - UFPI, at the *Professora Cinobelina Elvas* Campus (CPCE), Bom Jesus - PI, located at the geographical coordinates: 09° 05’32" South latitude and 44º 20’32" East longitude and altitude of 277 m. The climate of the region is sub-humid dry, according to the classification of Thornthwaite, and has average rainfall between 900 and 1200 mm year^{-1} with an average temperature of 26.5 ºC (MEDEIROS; ALVES., 2016). The temperature during the day peaks at 44.70 ºC in the hottest months of the year (INMET, 2019). The average values of air temperature and relative humidity in the greenhouse during the experimental period are shown in Figure 1.

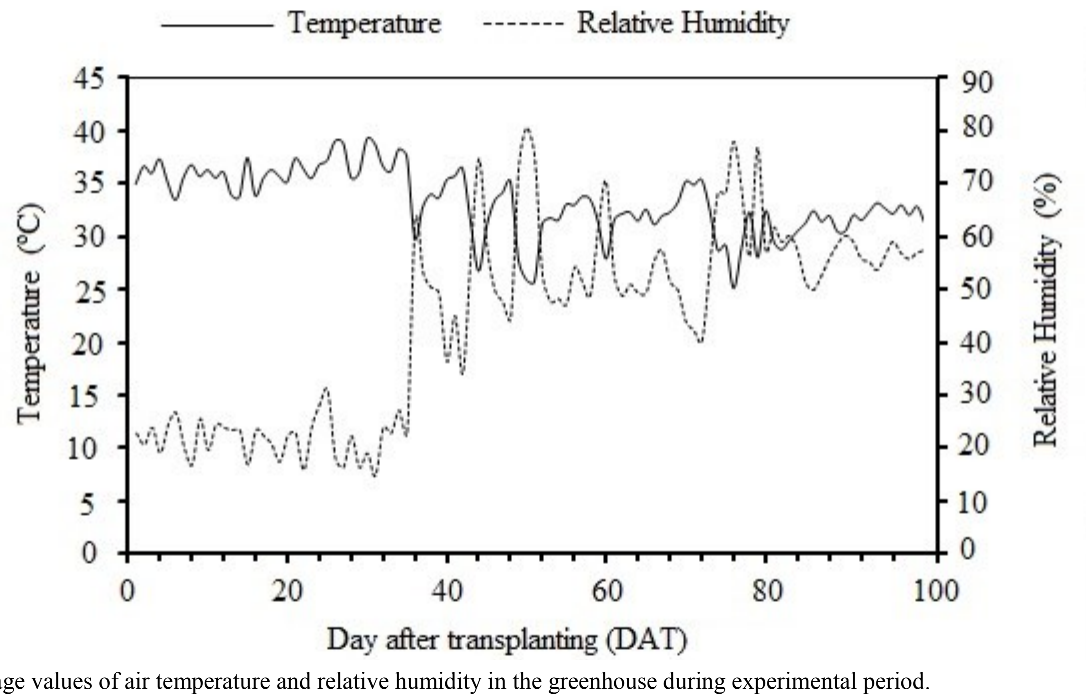

Figure 1. Average values of air temperature and relative humidity in the greenhouse during experimental period.

The design adopted was randomized blocks with four replicates, in a 6 x 2 factorial scheme, corresponding to six salinity levels of irrigation water, ECw (1.05; 2.12; 3.26; 4.41; 5.91 and 7.32 dS m^{-1}) with and without foliar application of Si. Each experimental unit was composed of one plant, cultivated in 8-L polyethylene pot filled with 1.0 L with crushed stone no. 1 and the remainder with commercial substrate, Carolina Soil Padrão II®, composed of Sphagnum peat moss, expanded vermiculite, torrefied rice husk and fertilizers (macro and micronutrients), with EC = 0.7 dS m^{-1} and pH = 6.5 ± 0.25, separated from the crushed stone by a thin screen of polyethylene. As a source of Si, sodium silicate was adopted at a concentration of 2.0 mmol L^{-1} of Si as a function of solubility in water of mono silicic acid (H_4SiO_4).

The studied crop was mini watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai), Smile hybrid, cultivated in a 36 m² greenhouse, covered by a 150-micron-thick transparent polyethylene film and protection on the sides, with white polypropylene screen (Sombrite®) with 30% shading. The seedlings were propagated in expanded polystyrene trays composed of 128 cells, filled with Carolina Padrão II® substrate and irrigated by capillary rise, in a specially prepared reservoir with controlled water volume, where the tray was put in twice a day. At 25 days after sowing, the seedlings were transplanted into the pots when they had 4 to 5 true leaves, one plant per pot.

At 15 days after transplanting, the plants were vertical staked with a nylon cord fixed in a ceramic block under the bucket with the substrate, extended to a wire no. 14 fixed to the wooden frame of the screen above each block, at a height of approximately 2 m. Weekly, the lateral branches that appeared at the base of the stem were pruned with pruning shears, keeping only one main branch from the base of the stem, and the staking continued.

Irrigation was applied by a drip system, using pressure-compensating emitters, with a nominal flow rate of 4 L h^{-1}, connected to irrigation lines (16-mm-diameter polyethylene pipes) with valves installed at the beginning of each line, which allowed the application of different concentrations of salts per treatment. The system was also composed of a 0.5-HP pump, with manometer and coupled filtration systems. Irrigation was controlled by means of a timer programmed daily according to ETo (Reference Evapotranspiration – FAO), calculated based on the agrometeorological data of the previous day, using the crop coefficients for the mini watermelon crop. Data referring to agrometeorological variables were collected by a thermo-hygrometer, located inside the greenhouse where the physical experiment was conducted, and later correlated with the data provided by the weather station located on the UFPI campus (INMET) to create an equation of standardization and then calculate ETo. Irrigation was distributed in eight periods during the day, concentrating most of the water depth at the hottest times of the day and a smaller portion at the beginning and end of the day in order to avoid excessive drainage in the pots.

A weekly fertigation through injection was performed directly by the pump installed in the fertigation tank corresponding to each level of salinity. Fertilizers were applied together with irrigation water, 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 and Magnesium Sulfate, while Sodium Silicate was foliar applied, at a concentration of 25 mL of the solution per liter of water once a week, for four weeks, using a 1.5-L sprayer and a 1.5-m-high plastic curtain around the plant that received the application so as not to interfere with the others. The electrical conductivity of the solution in treatments with Si and without Si addition was predicted according to the amount of dissolved salts, and adjusted according to the test performed using a portable conductivity meter. Fertigation management was based on the nutrient application rate for the crop proposed by Medeiros and Alves (2016). Regarding the chemical composition of the fertilizer salts, the reference adopted was the recommendation of fertilization for the cultivation of mini watermelon described by Moraes (1997). The sources of macronutrients used were: MAP - Monoammonium Phosphate, Potassium Nitrate, Calcium Nitrate and Magnesium Sulfate, and the amounts applied are detailed in Table 1.

Table 1. Amount of nutrients (g $plant^{-1}$), applied throughout the mini watermelon cultivation cycle, for fertigation management, in the absence and presence of foliar-applied silicon.

SL# (dS m^{-1})	$NH_4H_2PO_4$	KNO_3	$Ca(NO_3)_2$	$MgSO_4$	TOTAL
	-----Absence and presence of silicon-----				
S1 = 1.05	15.88	33.85	22.49	15.21	87.44
S2 = 2.12	31.76	67.71	44.99	30.42	74.87
S3 = 3.26	47.64	101.56	67.48	45.63	262.31
S4 = 4.41	63.52	135.41	89.98	60.84	349.75
S5 = 5.91	79.40	169.26	112.47	76.05	437.19
S6 = 7.32	95.29	203.12	134.96	91.26	524.62
TOTAL	333.50	710.90	472.40	319.40	1,736.20

SL# = Salinity Levels.

At 74 days after transplanting (DAT), when the fruits were harvested, the following parameters were evaluated: plant height (cm) with a measuring tape; stem diameter (mm) by means of a digital caliper (727-2001; Starrett, Athol, Massachusetts, USA); number of leaves per plant; and number of fruits per plant. Then, an analytical scale with accuracy of 0.01 g was used to evaluate leaf fresh mass (g) and stem fresh mass (g). Subsequently, these plant parts (stem and leaves of the same plant) were separately placed in paper bags identified with the respective treatments, fixed together using a stapler, and dried in a forced air circulation oven at a temperature of 65 ± 1 °C, for 72 hours, in the Plant Propagation Laboratory (UFPI -CPCE) until reaching constant dry mass, when they were weighed again on a precision scale (0.01 g accuracy) to obtain leaf dry mass (g) and stem dry mass (g).

In addition, the following parameters were evaluated: fruit diameter (cm), with a measuring tape; fruit weight (g), on an analytical scale with accuracy of 0.01 g; peel thickness (mm), measured in the equatorial region of the fruits with a digital caliper; pulp weight (g); number of seeds; total soluble solids content (ºBrix), measured in a rubberized refractometer with focus adjustment (OKSN brand); and fruit firmness, determined by the average of three readings performed with a manual benchtop penetrometer with 8-mm tip in the central region of the fruits cut in the longitudinal direction, with values in kgf that were converted to N (Unit of SI), through a multiplication by 9.80665.

The dry leaves and stem were ground in a Wiley-type mill (TECNAL - TE-650) and, after grinding, the samples of each treatment were placed in a 50-ml polyethylene flask with lid and identified according to the respective treatment. The procedure for the analyses was based on dry digestion. Ca, Mg and micronutrient contents were determined by atomic absorption spectrometry, P and Si contents were determined by UV/VIS spectrophotometry, and K content was determined by flame photometry.

The data were subjected to analysis of variance by the F test ($P<0.05$). For the use of Si, the means were compared by Tukey test ($P<0.05$), while the water salinity levels were analyzed by polynomial regression, adopting the significant model with best fit and highest coefficient of determination, using Sisvar software (FERREIRA, 2011).

RESULTS AND DISCUSSION

It was observed by the summary of the analysis of variance (Table 2) that the conditions with and without foliar application of Si, for salinity levels and the interaction between Si application and irrigation water salinity, did not exert significant effects on the analyzed variables (PH, SD and NL) of mini watermelon cv. Smile. However, in a study carried out with the same crop, these variables were reduced when plants were subjected to levels of 5 dS m^{-1} (SOUSA et al., 2016), hence pointing to the need for further studies in this regard.

Table 2. Summary of the analysis of variance for plant height (PH), stem diameter (SD) and number of leaves (NL), pulp weight (PW), peel thickness (PT), total soluble solids (TSS) and number of seeds (NS) in the mini watermelon crop cv. Smile subjected to different levels of salinity in fertigation with and without foliar application of silicon.

SV	Mean Square						
	PH	SD	NL	PW	PT	TSS	NS
	cm	mm	unit	g	mm	ºBrix	unit
Silicon (Si)	402.52ns	0.15ns	22.68ns	1925.3ns	8.08*	10.26**	426.02ns
Salinity (S)	212.38ns	0.11ns	56.62ns	22770.1**	2.37ns	8.11**	1328.33ns
Si x S	242.32ns	0.29ns	17.78ns	4867.9ns	3.01ns	0.71ns	323.17ns
Mean							
With silicon	195.83	5.55	43.54	700.08	7.13 a	9.17 a	93.91
Without silicon	190.04	5.66	42.16	712.75	6.31 b	8.25 b	87.95
CV (%)	11.15	7.55	12.26	11.07	16.93	10.83	30.76

SV = Source of variation, CV = Coefficient of variation, ns = not significant, * significant ($p\leq0.05$) and ** significant ($p\leq0.01$) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ from each other by Tukey test at 5% probability level.

Plants that received Si applications were significantly superior to those that did not receive this treatment only in terms of peel thickness ($p\leq0.05$) and TSS ($p\leq0.001$) (Table 2). The isolated effect of salinity significantly influenced pulp weight and TSS ($p\leq0.01$). However, the interaction between treatments with and without Si and water salinity did not influence any of the variables evaluated. It was also observed that the factors foliar applications with and without Si and irrigation water salinity did not have significant results for the number of seeds in mini watermelon cv. Smile.

The variables PT and TSS of the fruits showed average increments of 12.99 and 11.15%, respectively, when plants were subjected to foliar application of Si (Figures 2 A and B). This increase with the use of Si is due to the increase in the photosynthetic rate stimulated by Si in plant tissue, leading to better absorption and mobility in the plant of macro- and micronutrients essential to crop development. This average increment in peel thickness with Si application also favors the transport and storage of fruits, giving them a longer shelf life.

The application of Si contributes to the homeostasis of the elements, modification of gas exchange attributes and osmotic adjustment, regulates the synthesis of compatible solutes, and stimulates antioxidant enzymes and gene expression in plants. In addition, the application of Si reduces the absorption and translocation of Na^{+} and increases absorption and translocation of K^{+} under salt stress; however, these mechanisms vary according to species, genotype, growth conditions, imposed duration of stress, among others (RIOS et al., 2017). In other crops, such as strawberry cultivars (Kurdistan), Si also increased ºBrix by 15.53% (YAGHUBI et al., 2019).

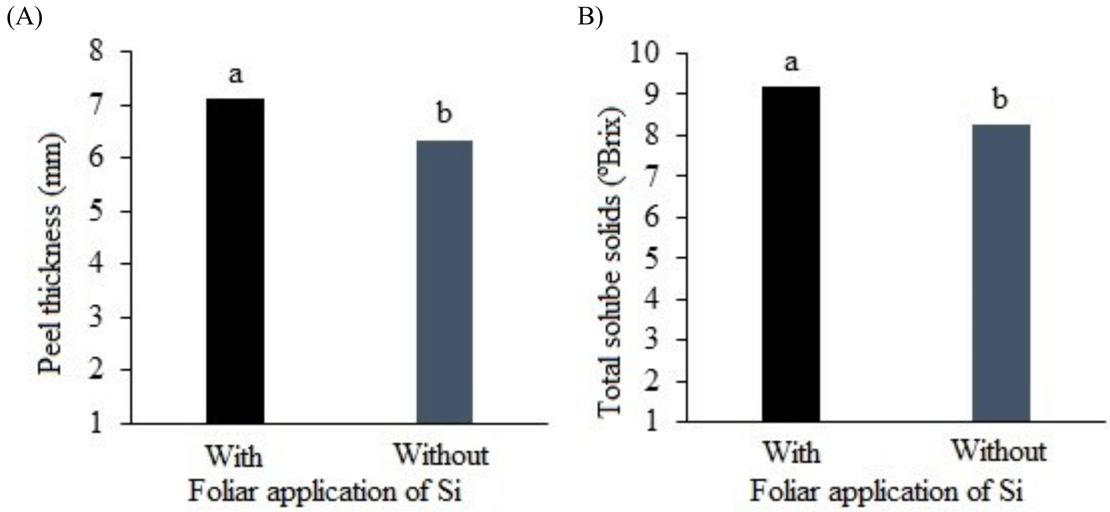

Figure 2. Mean values of peel thickness (mm) (A) and total soluble solids (ºBrix) of mini watermelon with foliar application of Si. Means followed by the same letter between columns do not differ from each other by Tukey test at 5% probability level.

According to Siddiqui et al. (2018), fertilization with Si also influences plant architecture, increasing the exposure of leaves to light, thus favoring photosynthesis. Similar results were reported by Soleimannejad, Abdolzadeh and Sadeghipour (2019), who evaluated a halophyte species (*Puccinellia Distans*), with Si application and under salt stress, and observed increments in dry mass and water relations.

The increase in irrigation water salinity caused a quadratic response in pulp weight, with a maximum value of 756.81 g at EC of 4.95 dS m^{-1} (Figure 3), with a decrease for this variable from this point on. This is due to the fact that the mini watermelon cv. Smile is moderately sensitive to salinity of irrigation water (SOUSA et al., 2016). Duarte and Souza (2016), in an experiment with bell pepper, under protected environment conditions and different salinity levels of irrigation water, observed that the smallest difference in total potential between the plant and the soil promoted higher water consumption by the plants and, in turn, greater fruit pulp weight.

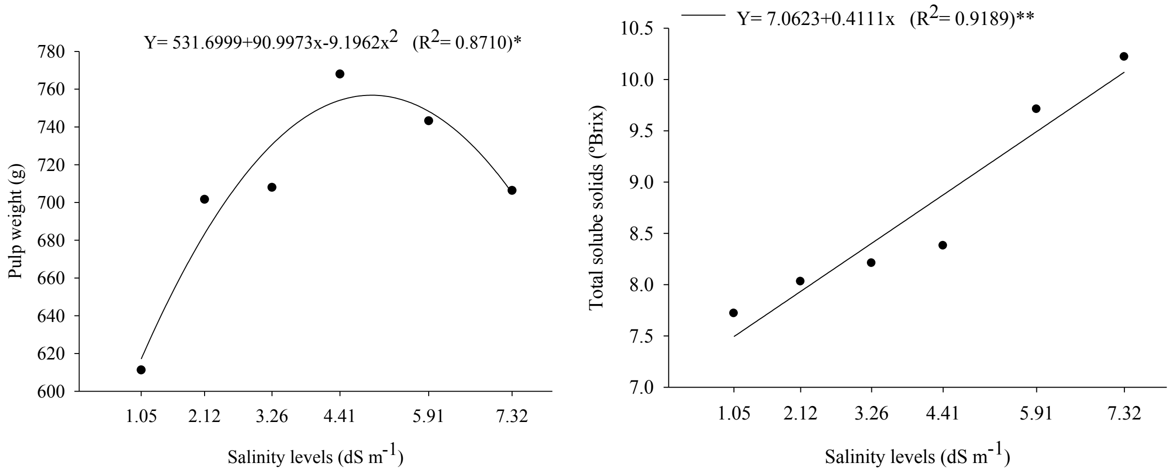

Figure 3. Pulp weight (A) and total soluble solids (B) in fruits of mini watermelon under increasing levels of salinity of irrigation water (fertigation). ** and * significant at 1% and 5%, respectively.

The increase of salinity in irrigation water promoted a linear increase in total soluble solids (ºBrix) in mini watermelon, causing maximum value in plants irrigated with water of 7.32 dS m^{-1}, with an increase of 5.82% for each unit increase in ECw (Figure 3). The increase in salinity levels of irrigation water reduced water absorption by the plant, promoting a higher concentration of total soluble solids in the fruits. Melo Filho et al. (2019), when studying beet crop under salinity levels and Si application, observed a linear increase in TSS with 15.7 ºBrix at the ECw of 6.0 dS m^{-1}. In tomato plants, Costan et al. (2020) also observed that TSS was significantly higher in plants grown under salinity (50 mM NaCl), regardless of the application of Si, corroborating the results found in the present study.

The results obtained in the analysis of variance for the plant and fruit traits of mini watermelon are presented in Table 3. For the factor represented by foliar application of Si, significant effects were observed only on leaf fresh mass and leaf dry mass ($p \leq 0.01$). For the factor represented by salinity of irrigation water, there was a significant effect only on fruit weight ($p \leq 0.01$) and, for the interaction between the above-mentioned factors, there was no significant effect on any of the variables evaluated.

Table 3. Summary of the analysis of variance for fruit firmness (FF), leaf fresh mass (LFM), leaf dry mass (LDM), stem fresh mass (SFM), stem dry mass (SDM), fruit diameter (FD) and fruit weight (FW) in mini watermelon cv. Smile subjected to salinity levels (ECw) fertigated with and without foliar application of silicon.

SV	Mean Square						
	FF	LFM	LDM	SFM	SDM	FD	FW
	N	g	g	g	g	cm	g
Salinity (S)	0.019^{ns}	3640.08^{**}	50.02^{**}	27.00^{ns}	0.18^{ns}	0.36^{ns}	17671.6^{ns}
Silicon (Si)	2.30^{ns}	204.33^{ns}	11.41^{ns}	41.40^{ns}	3.42^{ns}	1.04^{ns}	59157.0^{**}
S x Si	1.63^{ns}	542.88^{ns}	18.76^{ns}	26.25^{ns}	0.25^{ns}	0.92^{ns}	7605.8^{ns}
Mean							
With silicon	6.18	86.12 a	15.19 a	39.62	5.09	12.64	992.20
Without silicon	6.22	68.70 b	13.15 b	38.12	4.96	12.47	953.83
CV (%)	23.86	23.18	29.22	18.31	36.95	9.12	10.66

SV = Source of variation, CV = Coefficient of variation, ns = not significant, * significant ($p \leq 0.05$) and ** significant ($p \leq 0.01$) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ from each other by Tukey test at 1 or 5% probability level.

Plants that received foliar application of Si showed increments of 25.36 and 15.51% for leaf fresh mass and leaf dry mass, respectively (Figures 4 A and B). This is related to the mechanical protection, mainly attributed to the deposition of Si in the form of amorphous silica (SiO_2 nH_2O) in the cell wall of the leaves, near the transpiration organs, forming a lignified double layer below the cuticle, due to foliar fertilization with Si (TORRES et al., 2015). Abe (2019), when studying Cucurbitaceae, observed the Si deposited in the trichome and in the cells surrounding the bases of watermelon leaves, which is associated with the greater structural rigidity of the tissues, leaving the leaves more erect and increasing the photosynthetic area, hence promoting greater water absorption (FÁTIMA et al., 2019).

For fruit weight (Figure 5), an increasing quadratic polynomial fit was obtained, with maximum of 1051.42 g at the salinity level of 6.50 dS m^{-1}, which suggests that this cultivar is moderately tolerant to salinity.

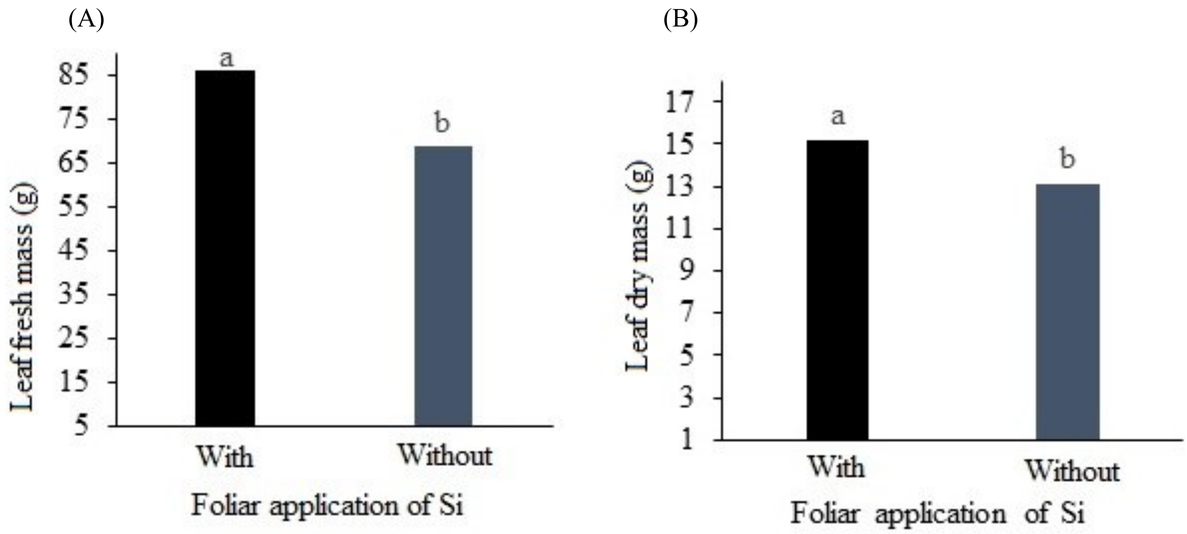

Figure 4. Mean values of leaf fresh mass per plant (A) and leaf dry mass per plant (B) of mini watermelon with and without foliar application of silicon. Means followed by the same letter between columns do not differ from each other by Tukey test at 5% probability level.

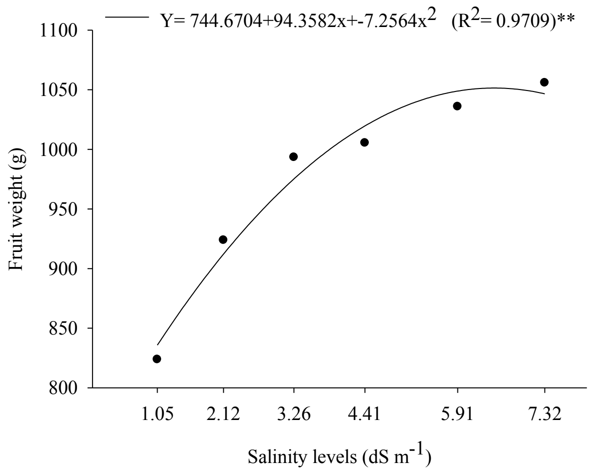

Figure 5. Weight of mini watermelon fruits under increasing levels of water salinity via fertigation. ** and * significant at 1% and 5%, respectively.

It is important to highlight that, although soil salinity reduces the availability of water in the soil, crops do not respond equally to the negative effects of salts, as some are more tolerant than others and can extract water more easily. However, Sousa et al. (2016) found that the mini watermelon cv. Smile has characteristics of moderately sensitive to salinity of irrigation water, because they observed reductions of 4.5% in plant height, 8.5% in leaf fresh mass and 4.3% in leaf dry mass for each unit increase in water salinity.

The results obtained in the analysis of variance for the contents of macro and micronutrients in the leaf of mini watermelon plants are presented in Table 4. For the nutrient contents in the mini watermelon leaf, there was no significant interaction between the factors foliar application of Si and salinity of irrigation water. For the foliar application of Si, there were significant effects only on the Si micronutrient ($p \leq 0.01$). For the salinity of irrigation water, there were significant effects on manganese (Mn) and zinc (Zn).

Table 4. Summary of the analysis of variance for calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), copper (Cu), manganese (Mn), iron (Fe), zinc (Zn) and silicon (Si) contents in the leaves of mini watermelon cv. Smile subjected to salinity levels (ECw) fertigated with and without foliar application of silicon.

SV	Mean Square								
	Ca	Mg	P	K[1]	Cu	Mn	Fe	Zn	Si
	------ mg kg^{-1} -------		------- g kg^{-1} -------		------------------------- mg kg^{-1} ------------------------				---- g Kg^{-1} ----
Silicon (Si)	58.08^{ns}	4.02^{ns}	0.15^{ns}	6.97^{ns}	0.52^{ns}	6113.31^{ns}	17999.3^{ns}	22.14^{ns}	263188.5**
Salinity (S)	41.15^{ns}	45.75^{ns}	2.87^{ns}	2.31^{ns}	4.02^{ns}	24389.6**	6975.7^{ns}	1044.3*	13334.9^{ns}
Si x S	162.68^{ns}	7.69^{ns}	2.74^{ns}	4.55^{ns}	1.06^{ns}	4681.5^{ns}	2877.8^{ns}	60.80^{ns}	14283.6^{ns}
Mean									
With Silicon	57.65	42.22	4.64	12.60	6.21	388.87	250.14	54.47	453.84 a
Without Silicon	59.85	42.80	4.75	13.36	6.00	411.44	288.87	53.11	305.74 b
CV (%)	14.94	13.94	33.65	22.33	26.08	20.78	30.62	27.47	28.14

SV = Source of variation, CV = Coefficient of variation, ns = not significant, * significant ($p \leq 0.05$) and ** significant ($p \leq 0.01$) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ from each other by Tukey test at 5% probability level. [1] (20x) g kg^{-1}.

Mini watermelon plants that received foliar application of Si showed an increase of 48.44% in the Si content in the leaves (Figure 6). Regarding the leaf content of Si, this significant increase with the foliar application of Si highlights the efficiency of the product in supplying Si to the mini watermelon crop, confirmed by the variables of plant growth and fruit quality, such as leaf fresh mass and leaf dry mass (Figures 4 A and B), PT and TSS (Figures 2 A and B), respectively.

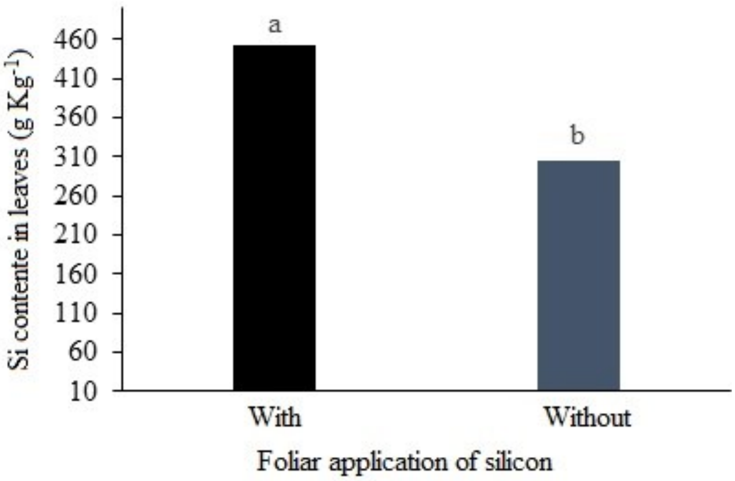

Figure 6. Mean values of silicon content in the leaves (g kg^{-1}) of mini watermelon as a function of foliar application of silicon. Means followed by the same letter between columns do not differ from each other by Tukey test at 5% probability level.

This result shows that the mini watermelon is not a Si accumulator, as Si-accumulator plants are those that accumulate more than 10 g kg^{-1} of Si and have a molar Si/Ca ratio greater than 1. Plants that contain 5 to 10 g kg^{-1} of Si in the dry mass, but have less than 1 in the molar Si/Ca ratio are defined as intermediate, and plants that contain less than 5 g kg^{-1} of Si, as non-Si accumulators (MA; TAKAHASHI, 1990). Nascimento et al. (2019) also observed a significant increase in Si accumulation in melon leaves, with a sharp increase up to the rate of 400 kg ha^{-1} of Si, followed by a slight but constant increase at the higher doses of Si.

For the manganese content in the leaves of mini watermelon (Figure 7), an increasing quadratic polynomial fit was obtained, with maximum of 448.40 g kg^{-1} at the salinity level of 4.85 dS m^{-1}. This result corroborates pulp weight (Figure 3), confirming that the mini watermelon cv. Smile is moderately sensitive to salinity of irrigation water, and is also consistent with the results reported by Sousa et al. (2012), who observed a 18.99% increase in Mn content in the leaves of jatropha irrigated with saline water of 3.0 dS m^{-1}.

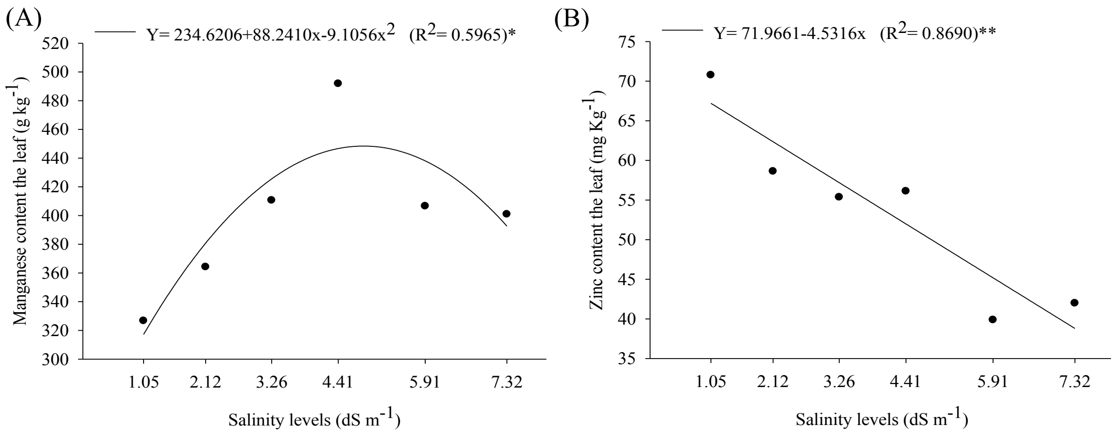

Figure 7. Manganese (A) and zinc (B) contents in the leaves of mini watermelon under increasing salinity levels of irrigation water via fertigation. ** and * significant at 1% and 5%, respectively.

The zinc content in the leaves of mini watermelon (Figure 7) under increasing levels of ECw showed a linear response with 6.30% decrease for each unit increase in ECw. This reduction in zinc accumulation in the leaf is caused by salt stress, leading to a reduction in the absorption of water and nutrients and, consequently, oxidative stress caused by nutritional imbalance (disordered increase or reduction) of reactive oxygen species (ROS) resulting from the deficiency of the micronutrient (SHARMA; KUMAR; TEWARI, 2004). Salinity is one of the most limiting abiotic stresses to plant production (SANTOS et al., 2020), resulting from natural or anthropic processes, such as irrigation and fertilization (ONODERA et al., 2019).

Foliar applications of Si did not influence the macronutrients evaluated in the stem of mini watermelon. Salinity of irrigation water significantly affected only potassium (K) content ($p \leq 0.05$). There was no significant interaction between these two factors (Table 5).

Table 5. Summary of the analysis of variance for calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), copper (Cu), manganese (Mn), iron (Fe), zinc (Zn) and silicon (Si) contents in the stem of mini watermelon cv. Smile subjected to salinity levels (ECw) fertigated with and without foliar application of silicon.

SV	Mean Square								
	Ca	Mg	P	K[1]	Cu	Mn	Fe	Zn	Si
	------ mg kg^{-1} ------		------- g kg^{-1} -------		----------------------- mg kg^{-1} -----------------------				g kg^{-1}
Silicon (Si)	4.56^{ns}	4.26^{ns}	8.50^{ns}	0.90^{ns}	0.08^{ns}	199.67^{ns}	505.05^{ns}	41.81^{ns}	3798.50*
Salinity (S)	2.64^{ns}	10.08^{ns}	7.49^{ns}	319.46*	1.19^{ns}	118.38^{ns}	1163.7^{ns}	83.66^{ns}	277.20^{ns}
Si x S	10.63^{ns}	1.57^{ns}	0.57^{ns}	83.3^{ns}	0.51^{ns}	2689.1**	246.60^{ns}	166.56^{ns}	125.00^{ns}
Mean									
With Silicon	11.97	21.75	5.61	32.64	5.00	120.03	55.00	38.01	88.43 a
Without Silicon	11.35	22.34	6.45	32.36	4.92	115.95	61.49	36.14	70.64 b
CV (%)	14.97	11.94	24.55	25.57	24.87	14.33	37.38	39.31	24.13

SV = Source of variation, CV = Coefficient of variation, ns = not significant, * significant ($p \leq 0.05$) and ** significant ($p \leq 0.01$) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ from each other by Tukey test at 5% probability level. [1] (20x) g kg^{-1}.

The potassium content in the stem of mini watermelon under salinity levels of fertigation (Figure 8) showed an increasing linear response, with 10.48% increment for each increase in ECw, corroborating the results for ºBrix (Figure 3), which showed a positive response with increasing water salinity. This result confirms those found by Sousa et al. (2012), who evaluated jatropha plants under salinity and observed increments in K content of 12.71, 19.44, 20.18 and 14.97% when irrigating using water with ECw of 1.2, 1.8, 2.4 and 3.0 dS m^{-1}, respectively, compared to the ECw of 0.6 dS m^{-1}.

For the results of micronutrient contents present in the mini watermelon stem, foliar application of Si had a significant effect only on Si (g kg^{-1}) ($p \leq 0.05$). For the salinity of irrigation water, there was no significant effect on any variable evaluated. In the interaction between the factors foliar application of Si and salinity of irrigation water, there was a significant response only for manganese (Mn) ($p \leq 0.01$) (Table 5).

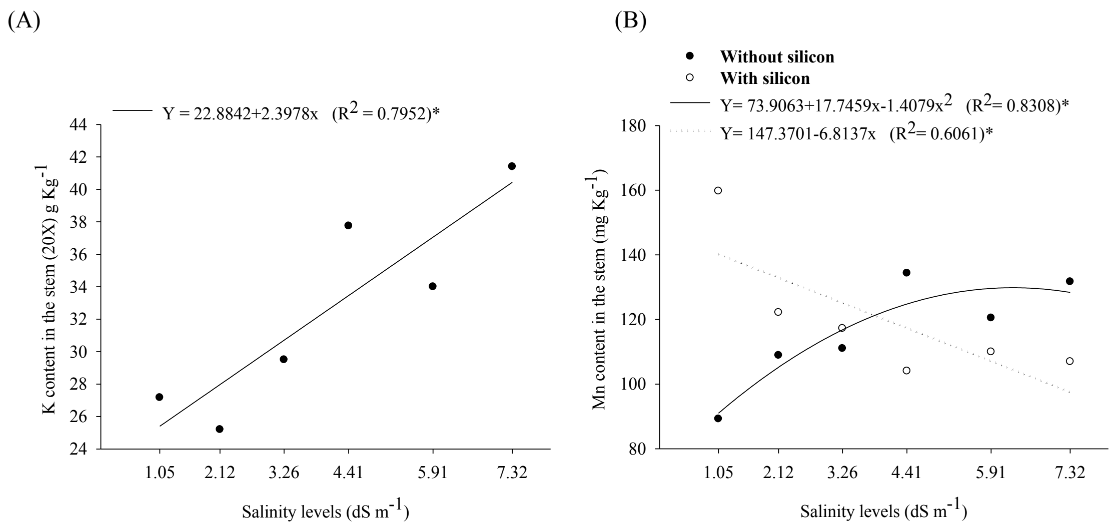

Figure 8. Potassium content (A) in the stem of mini watermelon under increasing salinity levels of irrigation water via fertigation; manganese content (B) in the stem of mini watermelon as a function of the interaction between foliar application of silicon and salinity levels of irrigation water. ** and * significant at 1% and 5%, respectively.

Regarding the interaction between foliar application of Si and salinity of irrigation water for the manganese micronutrient, a decreasing linear response was obtained for the foliar application of Si with increasing salinity of fertigation, with a decrease of 4.62% for each increase in ECw, whereas in the absence of foliar application of Si, a quadratic response was observed with increasing salinity in fertigation, with a maximum value of 129.83 mg kg^{-1} of Mn at the ECw of

6.30 dS m^{-1} (Figure 8B), followed by a reduction in this variable from this point on. It can be observed that foliar application of Si in mini watermelon plants under salt stress reduces the accumulation of Mn in the stem, that is, the combination of Si application with salt stress led to lower Si content in mini watermelon stem.

Foliar application of Si promoted a 25.18% higher Si content in the stem of mini watermelon plants compared to plants that did not receive foliar application of Si (Figure 9).

In a very similar way to what occurred in the leaves of mini watermelon, the Si was absorbed and incorporated into the intercellular spaces of the stem through its polymerization, promoting the increase of its resistance and creating a rigid barrier, hence strengthening the cell wall and promoting better conditions so that they can withstand adversities such as salt stress and water deficit, which can cause a reduction in production depending on the time of occurrence and the duration period (MA, 2004).

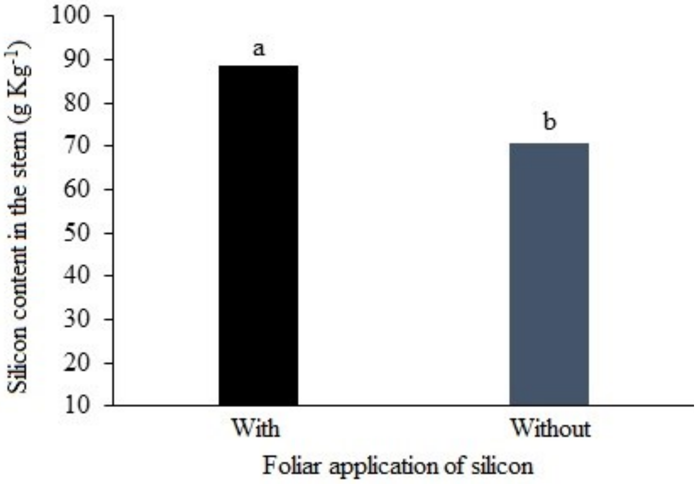

Figure 9. Mean values of silicon content in the stem (g kg^{-1}) of mini watermelon with foliar application of silicon. Means followed by the same letter between columns do not differ from each other by Tukey test at 5% probability level.

CONCLUSION

The use of silicon associated with fertigation with different levels of water salinity promoted better production performance for peel thickness, ºBrix, leaf fresh and dry mass and higher accumulation of silicon in the leaves and stem. Water salinity alone promotes increments in pulp weight and ºBrix of the fruits, as well as in the contents of manganese and potassium, besides inhibiting zinc contents in the leaves and stem of hybrid mini watermelon cv. Smile. Foliar application of silicon does not mitigate salt stress on mini watermelon.

REFERENCES

ABE, J. U. N. Silicon Deposition in Leaf Trichomes of Cucurbitaceae Horticultural Plants: A Short Report. **American Journal of Plant Sciences**, 10: 486-490, 2019.

AZAD, N. et al. Corrigendum to developing an optimization model in drip fertigation management to consider environmental issues and supply plant requirements. **Agricultural Water Management**, 208: 344–356, 2018.

BARRETO, R. F. et al. Accompanying ions of ammonium sources and nitrate: ammonium ratios in tomato plants. **Acta Agriculturae Scandinavica, Section B - Soil and Plant Science**, 181: 1-6, 2018.

BEZERRA, F. M. L. et al. Aspectos produtivos da melancieira sob irrigação com déficit e diferentes coberturas utilizando o modelo isareg. **Revista Caatinga**, 30: 437-446, 2017.

COSTAN, A. et al. Interactive effects of salinity and silicon application on Solanum lycopersicum growth, physiology and shelf-life of fruit produced hydroponically. **Journal of the Science of Food and Agriculture**, 100: 732-743, 2020.

DUARTE, H. H. F.; SOUZA, E. R. Soil water potentials and Capsicum annuum L. under salinity. **Revista Brasileira de Ciencia do Solo**, 40: 1-11, 2016.

FÁTIMA, R. T. et al. Adubação silicatada como atenuante do estresse hídrico no crescimento e trocas gasosas do alface. **Revista Engenharia na Agricultura**, 27: 170-178, 2019.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, 35: 1039-1042, 2011.

INMET - Instituto Nacional de Meteorologia. **Estação meteorológica A326 de Bom Jesus, PI**. 2019. Disponível em: http://www.inmet.gov.br/sonabra/pg_dspDadosCodigo_sim.php?QTMyNg. Acesso em: 19 Jun. 2020.

ISLAM, W. et al. Silicon-mediated plant defense against pathogens and insect pests. **Pesticide Biochemistry and**

Physiology, 168: 1-21, 2020.

MA, J. F.; TAKAHASHI, E. The effect of silicic acid on rice in a P deficient soil. **Plant Soil**, 126: 121-125, 1990.

MA, J. F. Role of Silicon in Enhancing the Resistance of Plants to Biotic and Abiotic Stresses. **Soil Science and Plant Nutrition**, 50: 11-18, 2004.

MANTOVANI, C.; PRADO, R. M.; PIVETTA, K. F. L. Silicon foliar application on nutrition and growth of *Phalaenopsis* and *Dendrobium* orchids. **Scientia Horticulturae**, 241: 83-92, 2018.

MEDEIROS, R. D.; ALVES, A. B. **Informações técnicas para o cultivo de melancia em Roraima**. Boa Vista, RR: Embrapa, 2016. 48 p.

MELO FILHO, J. S. et al. Effect of preharvest application of silicon and saline water on postharvest quality of beet (*Beta vulgaris* L.). **Journal of Experimental Agriculture International**, 32: 1-9, 2019.

MORAES, C. A. G. **Hidroponia: como cultivar tomates em sistema NFT (técnica de fluxo laminar de nutrientes)**. 1. ed. Jundiaí, SP: DISK, 1997. 141 p.

NASCIMENTO, C. W. A. et al. Influence of silicon fertilization on nutrient accumulation, yield and fruit quality of melon grown in northeastern Brazil. **Silicon**, 12: 937-943, 2019.

ONODERA, M. et al. Regulation of root-to-leaf Na and Cl transport and its association with photosynthetic activity in salt-tolerant soybean genotypes. **Journal Plant Production Science**, 22: 262-274, 2019.

RAJENDRAN, M.; IRENE, A. Efficient nutrient management through fertigation. In: GOYAL, M. R.; ALADAKATTI, B. K. (Eds). **Engineering interventions in sustainable trickle irrigation: water requirements, uniformity, fertigation, and crop performance**. Waretown, NJ: Apple Academic Press, 2018. v. 8, p. 101-117.

REYNOLDS, W. D. et al. Solute dynamics and the Ontario nitrogen index: II. Nitrate leaching. **Canadian Journal of Soil Science**, 96: 122-135, 2016.

RIOS, J. J. et al. Silicon-mediated improvement in plant salinity tolerance: the role of aquaporins. **Frontiers in Plant Science**, 8: 1-11, 2017.

SANTOS, L. J. D. S. S. et al. Efeito da salinidade na produção de mudas de pimentão. **Brazilian Journal of Development**, 6: 29354-29363, 2020.

SHARMA, P. N.; KUMAR, P.; TEWARI, R. K. Early signs of oxidative stress in wheat plants subjected to zinc deficiency. **Journal of Plant Nutrition**, 27: 451-463, 2004.

SIDDIQUI, H. et al. 24-Epibrassinolide supplemented with silicon enhances the photosynthetic efficiency of *Brassica juncea* under salt stress. **South African Journal of Botany**, 118: 120-128, 2018.

SILVA JÚNIOR, E. G. et al. Vegetative development and content of calcium, potassium, and sodium in watermelon under salinity stress on organic substrates. **Pesquisa Agropecuária Brasileira**, 52: 1149-1157, 2017.

SOLEIMANNEJAD, Z.; ABDOLZADEH, A.; SADEGHIPOUR, H. R. Beneficial effects of silicon application in alleviating salinity stress in halophytic *Puccinellia distans* plants. **Silicon**, 11: 1001-1010, 2019.

SOUSA, A. B. O. et al. Production and quality of mini watermelon cv. Smile irrigated with saline water. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 20: 897-902, 2016.

SOUSA, A. E. C. et al. Teores de nutrientes foliares e respostas fisiológicas em pinhão manso submetido a estresse salino e adubação fosfatada. **Revista Caatinga**, 25: 144-152, 2012.

TORRES, F. E. et al. Interação genótipo x ambiente em genótipos de feijão-caupi semiprostrado via modelos mistos. **Bragantia**, 74: 255-260, 2015.

VACULÍKOVÁ, M. et al. Influence of silicon on maize roots exposed to antimony e growth and antioxidative response. **Plant Physiological and Biochemistry**, 83: 279-284, 2014.

YAGHUBI, K. et al. Potassium silicate improves salinity resistant and affects fruit quality in two strawberry cultivars grown under salt stress. **Communications in Soil Science and Plant Analysis**, 50: 1439-1451, 2019.

WANG, H. et al. Optimal drip fertigation management improves yield, quality, water and nitrogen use efficiency of greenhouse cucumber. **Scientia Horticulturae**, 243: 357-366, 2019.

ZUSHI, K.; MATSUZOE, N. Using of chlorophyll, a fluorescence OJIP transient for sensing salt stress in the leaves and fruits of tomato. **Scientia Horticulturae**, 219: 216-221, 2017.