Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252023v36n411rc

Morphophysiology and inorganic solutes in watermelon irrigated with brackish water in different planting systems

Morfofisiologia e solutos inorgânicos em melancia irrigada com água salobra em diferentes sistemas de plantio

Francisco B. da Silva Junior[1]*, Claudivan F. de Lacerda[2], Geocleber G. de Sousa[3], Jonnathan R. da S. Sales[2], Andreza de M. Mendonça[4]

[1]Department of Soil Sciences, Universidade Federal do Ceará, Fortaleza, CE, Brazil. [2]Department of Agricultural Engineering, Universidade Federal do Ceará, Fortaleza, CE, Brazil. [3]Rural Development Institute, Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, CE, Brazil. [4]Department of Phytotechnics, Universidade Federal do Ceará, Fortaleza, CE, Brazil.

ABSTRACT - Irrigation with brackish water reduces watermelon yield in the Brazilian semiarid region, requiring the establishment of management strategies that reduce the negative impacts caused by salt stress. The objective of this study was to evaluate the morphophysiology and concentration of inorganic solutes in watermelon crops subjected to different electrical conductivities of the irrigation water, using hardened seedlings or direct sowing. The experiment was conducted in the Baixo Acarau Irrigated Perimeter, in the state of Ceara, Brazil. A randomized complete block design was used, with split plots and four replications. The plots consisted of four electrical conductivity levels of the irrigation water (0.3, 1.5, 3.0, and 4.5 dS m^{-1}), and the subplots consisted of three planting systems: DS = direct sowing; TP1 = transplanting of seedlings produced with moderate-salinity water (1.5 dS m^{-1}), and TP2 = transplanting of seedlings produced with low-salinity water (0.3 dS m^{-1}). The following variables were analyzed: vegetative growth, leaf gas exchange, and inorganic solutes. The use of watermelon seedlings produced with moderate-salinity water does not result in higher salt tolerance during the vegetative growth stage. Na^+, Cl^-, and Ca^{2+} leaf concentrations increase as the salt stress level is increased, regardless of the planting method. However, plants from seedlings (TP1 and TP2) have higher Na^+ and Cl^- concentrations when subjected to high salinity levels. The direct sowing method resulted in better performance of growth variables, mainly under low salinity levels.

Keywords: *Citrullus lanatus*. Salinity. Acclimation.

RESUMO - A irrigação com águas salobras reduz o rendimento da melancia no semiárido brasileiro, sendo necessário estabelecer estratégias de manejo que reduzam os impactos negativos provocados pelo estresse salino. Objetivou-se avaliar a morfofisiologia e os teores de solutos inorgânicos da cultura da melancia submetida à diferentes condutividades elétricas da água de irrigação, utilizando-se mudas rustificadas ou semeadura direta. O experimento foi realizado no Perímetro Irrigado Baixo Acaraú, Ceará, Brasil. O delineamento experimental utilizado foi o de blocos ao acaso com parcelas subdivididas, com quatro repetições. As parcelas foram formadas por quatro condutividades elétricas da água de irrigação (0,3; 1,5; 3,0; e 4,5 dS m^{-1}) e as subparcelas por três métodos de plantio: DS = semeadura direta; TP1 = transplantio da muda produzida com água de moderada salinidade (1,5 dS m^{-1}), e TP2 = transplantio da muda produzida com água de baixa salinidade (0,3 dS m^{-1}). Analisou-se as variáveis de crescimento vegetativo, trocas gasosas foliares e os solutos inorgânicos. A utilização de mudas de melancia produzidas com a água de moderada salinidade não resulta em maior tolerância ao estresse salino durante a fase de crescimento vegetativo. Os teores foliares de Na^+, Cl^- e Ca^{2+} aumentam com o nível do estresse salino, independentemente do método de plantio. Entretanto, as plantas oriundas de mudas (TP1 e TP2) apresentam as maiores concentrações de Na^+ and Cl^- sob elevados níveis de salinidade. O método de plantio por semeadura direta apresentou superioridade nas variáveis de crescimento, principalmente sob baixos níveis de salinidade.

Palavras-chave: *Citrullus lanatus*. Salinidade. Aclimatação.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: August 3, 2022.
Accepted in: June 12, 2023.

***Corresponding author:**
<juniorbarroso_99@hotmail.com>

INTRODUCTION

Watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai.] is grown in several countries, with a global production of 102 million Mg and an area of 3.02 million hectares (FAOSTAT, 2021). In Brazil, watermelon is one of the most important crops and is grown in almost all states, mainly in the Northeast region (COSTA; MEDEIROS, 2018).

Watermelon planting is predominantly carried out through direct sowing, but several farmers have practiced the production of seedlings for transplanting. This is mainly due to reduction of costs with seeds and possibility of selecting more vigorous and uniform plants for a better establishment in the field (LIMA NETO et al., 2019).

Seedling production is one of the most important steps for successful agricultural productions, as the use of high-quality seedlings accounts for 60% of the success of the crop production (NATALE et al., 2018). Moreover, the quality of the irrigation water directly affects seedling production and development, making it a determining factor of crop yield (YAN et al., 2018; RIBEIRO et al., 2020).

High salt concentrations in irrigation waters, commonly found in the Northeast region of Brazil, is an important abiotic constraint, inhibiting plant growth and several physiological and biochemical processes, thus limiting crop yield. Excess salts in the root zone reduces stomatal conductance and photosynthesis rate, alters ion homeostasis in cells, and causes nutritional imbalance and a rapid accumulation of reactive oxygen species (JANDA et al., 2016; SILVA et al., 2019; SOUSA et al., 2022).

Therefore, improving plant tolerance to salt stress is one of the main current goals to achieve sustainable agriculture. Recent studies have shown that pre-exposure to moderate stress helps plants acclimate better to subsequent stress events (KAMANGA et al., 2020). This hardening can be obtained by pre-exposing plants to a moderate level before increasing salt levels that cause damage (JANDA et al., 2016).

In this context, the objective of this study was to evaluate the morphophysiology and inorganic solute contents in watermelon crops subjected to different electrical conductivity levels of the irrigation water, using hardened seedlings or direct sowing.

MATERIAL AND METHODS

The experiment was conducted between October and December 2020, in an area within the Baixo Acarau Irrigated Perimeter (3°07'13"S; 40°05'13"W), between the municipalities of Marco, Bela Cruz, and Acarau, in the state of Ceara, Brazil. The climate of the region is Aw', tropical rainy, according to the Köppen classification (1923). The climate data during the experimental period are shown in Figure 1.

The soil of the experimental area was classified as a Quartzipsamment (Entisol) (USDA, 2022). The soil physical and chemical characteristics are shown in Table 1.

The experiment was set in a split-plot randomized complete block design in a 4×3 factorial arrangement, with four replications, totaling 36 experimental units. The plots consisted of four electrical conductivity levels of the irrigation water (0.3, 1.5, 3.0, and 4.5 dS m^{-1}) and the subplots consisted of three planting methods (DS = direct sowing, TP1 = transplanting of seedlings produced with moderate-salinity water (1.5 dS m^{-1}), and TP2 = transplanting of seedlings produced with low-salinity water (0.3 dS m^{-1}).

The seedlings were produced in a protected environment with a 50% black mesh screen, using a substrate composed of bovine manure and soil (1:1), arranged in 200-cell 40 cm^3 expanded polystyrene trays. They were manually irrigated daily after sowing until the water drained through the trays' bottom (MAROUELLI; BRAGA, 2016). One watermelon seed (variety Crimson Sweet) was sown at 2 cm depth in each cell. The seedling production started simultaneously with direct sowing (DS) in the field so that the seedlings (TP1 and TP2) could be transplanted to the field 15 days after sowing (DAS). The direct sowing treatment was subjected to thinning at 21 DAS.

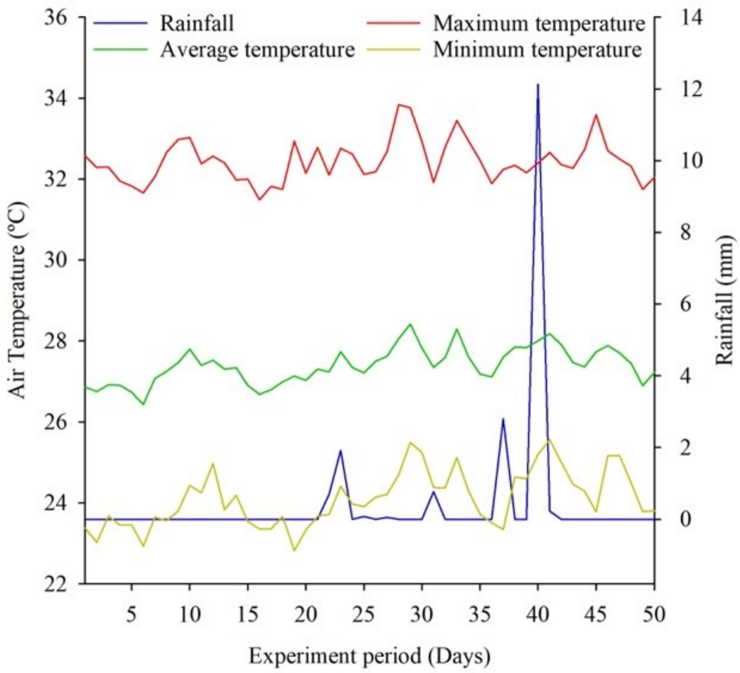


Figure 1. Data on climate conditions during the experimental period.

Table 1. Physical and chemical characteristics of the soil of the experimental area in the Baixo Acarau Irrigated Perimeter, Ceara, Brazil.

Physical characteristics		
Granulometric Composition (g Kg^{-1})	Coarse sand	668
	Fine sand	272
	Silt	29
	Clay	36
	Natural clay	14
Soil texture	Sandy	
Flocculation degree	(g 100 g^{-1})	62
Density (g cm^{-3})	Soil	1.49
	Particle	2.69
Chemical characteristics		
pH		6.3
ECse	(dS m^{-1})	0.13
OM	(g kg^{-1})	4.03
N	(g kg^{-1})	0.24
Ca^{2+}	($cmol_c$ kg^{-1})	1
K^+	($cmol_c$ kg^{-1})	0.07
Mg^{2+}	($cmol_c$ kg^{-1})	0.5
Na^+	($cmol_c$ kg^{-1})	0.09
$H^+ + Al^{3+}$	($cmol_c$ kg^{-1})	1.49
Al	($cmol_c$ kg^{-1})	0.05
SB	($cmol_c$ kg^{-1})	1.66
P	(mg kg^{-1})	15
CEC	($cmol_c$ kg^{-1})	3.15
BS	(%)	52.7
ESP	(%)	3

OM – organic matter; SB – sum of bases ($Ca^2 + Mg^{2+} + Na^+ + K^+$); CEC – cation exchange capacity – [$Ca^{2+} + Mg^{2+} + Na^+ + K^+ + (H^+ + Al^{3+})$]; BS – base saturation – ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$/ CEC) × 100; ECse – electrical conductivity of the saturation extract; ESP – exchangeable sodium percentage.

The irrigation management was based on climatology (ALLEN et al., 1998); the irrigation depths were defined based on the replacement of crop evapotranspiration (ETc), obtained by multiplying the crop coefficient (Kc) by the reference evapotranspiration (ETo). Crop coefficients of 0.30, 1.15, and 0.58 were used for the initial, intermediate, and final stages, respectively (MIRANDA; OLIVEIRA; SOUZA, 2004).

The electrical conductivity levels of the irrigation water (1.5, 3.0, and 4.5 dS m^{-1}) were obtained by adding the salts NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ for the low-salinity water (0.3 dS m^{-1}), at a ratio of 7:2:1, following the relations between electrical conductivity of water (ECw) and its concentration (mmolc L^{-1} = EC × 10) (RHOADES; KANDIAH; MASHALI, 2000). All treatments were irrigated after transplanting, using 0.3 dS m^{-1} water, to promote seedling establishment. Treatments with different salinity levels were started seven days after transplanting.

The following variables were evaluated at 50 DAS: main branch length (MBL; cm), measured from the base of the main branch, using a ruler tape; stem diameter (SD; mm), measured at 5 cm from the ground, using a digital caliper with a precision of 0.05 mm; and number of branches (NB), obtained by direct counting.

The following physiological indices were also evaluated at 50 DAS: stomatal conductance (*gs*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), and transpiration rate (*E*). These measurements were performed on mature leaves, using an IRGA device (LCi model, ADC, BioScientific, Hoddesdon, UK). Readings were carried out between 9:00 and 11:00 am, under environmental conditions of air temperature and CO_2 concentration, using an artificial light with 1,000 µmol m^{-2} s^{-1} and an airflow rate of 300 mL min^{-1}.

Shoot dry weight (SDW) was determined by placing samples in labeled paper bags and drying them in an oven at 65 °C. Shoots were ground in a Willey mill with 1 mm mesh, and the ground material was used to determine sodium, chloride, and calcium concentrations.

Na^+ and Ca^{2+} were obtained through dry digestion by incineration of plant tissue in an electric muffle furnace at 450 to 550 °C, followed by dissolution of the inorganic residue (ashes) in a 1 mol L^{-1} HNO_3 solution. Sodium readings were carried out using flame photometry, and Ca^{2+} was determined by atomic absorption spectrometry (MENEGHETTI, 2018). Chloride was determined through aqueous extract by titration with silver nitrate ($AgNO_3$), using potassium chromate as an indicator (MALAVOLTA; VITTI; OLIVEIRA, 1997).

The data were subjected to Kolmogorov-Smirnov normality test and, subsequently, to analysis of variance by the F test. Tukey's test was used to compare the means of seedling production systems, and regression analysis was used to assess the effect of salinity. The equations that best fit the data were selected based on the coefficient of determination (R^2). The statistical analyses were performed using the software ASSISTAT 7.7 Beta (SILVA; AZEVEDO, 2016).

RESULTS AND DISCUSSION

The analysis of variance showed a significant interaction between the irrigation water salinity and planting method for most evaluated variables (Table 2). However, stomatal conductance (*gs*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), and transpiration rate (*E*) were significantly affected only by the irrigation water salinity.

Table 2. Analysis of variance (mean square) for main branch length (MBL), number of branches (NB), stem diameter (SD), shoot dry weight (SDM), stomatal conductance (*gs*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), transpiration rate (*E)*, and sodium (Na^+), chloride (Cl^-), and calcium (Ca^{2+}) concentrations in leaves of Crimson Sweet watermelon plants as a function of different irrigation water salinity levels and planting methods.

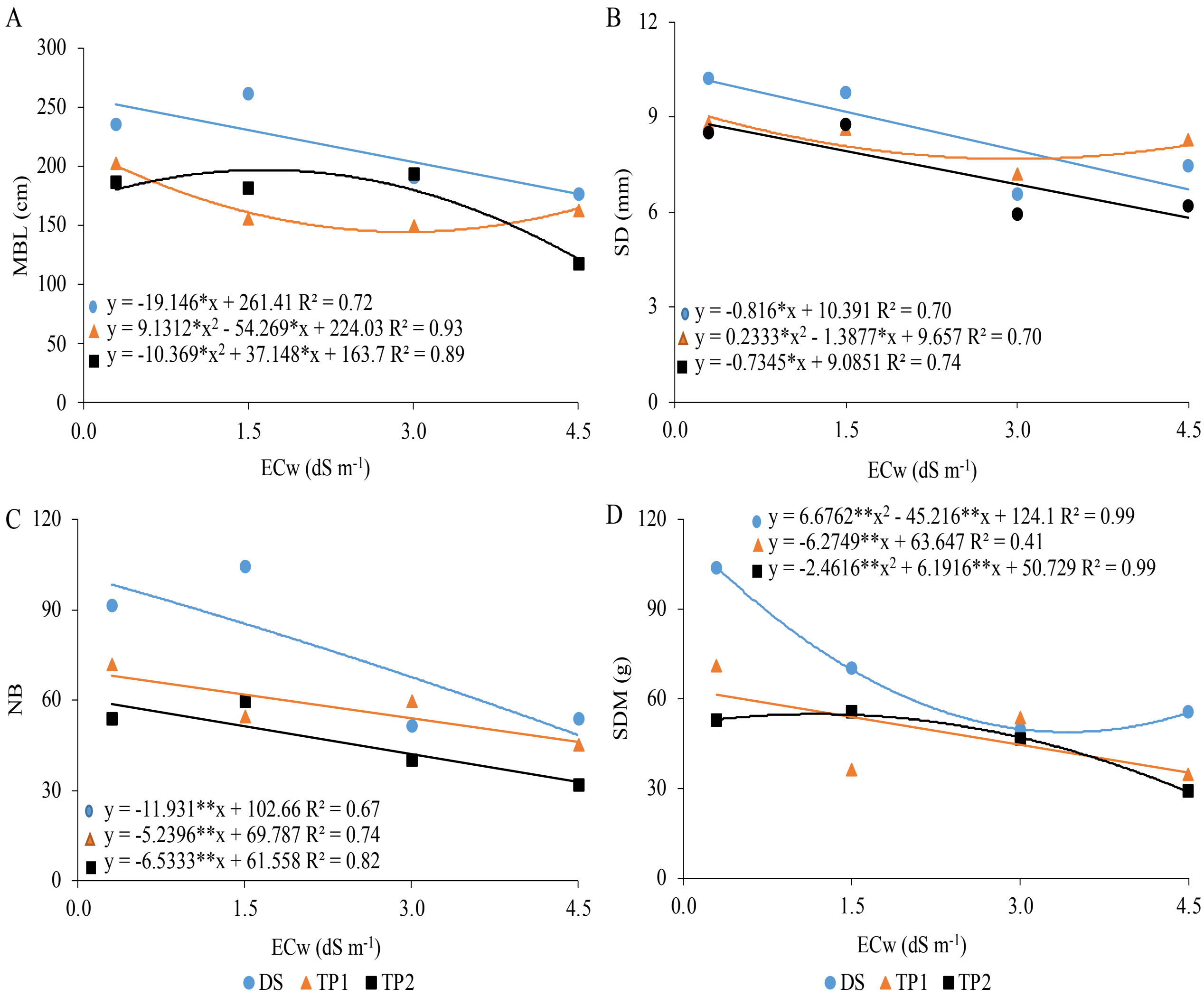
VS	DF	MBL	SD	NB	SDW	*gs*	*A*	*Ci*	*E*	Na^+	Cl^-	Ca^{2+}
Block	3	2,760.2^{ns}	15.3^{ns}	331.4^{ns}	20.3^{ns}	0.66*	77.8*	3,164.9*	0.6^{ns}	0.01^{ns}	8.1^{ns}	2.7^{ns}
SL (a)	3	7,481.2*	17.4^{ns}	2,298.7**	2,031.9**	0.644**	81.5*	4,330.9**	9.6**	0.09^{ns}	53.1*	460.7**
Error - a	9	1,525.3	7.1	175.3	284.4	0.028	15.0	489.8	0.7	0.03	9.2	12.4
PM (b)	2	11,954.5**	8.1**	3,224,8**	2,691.6**	0.001^{ns}	17.3^{ns}	284.8^{ns}	0.3^{ns}	0.02^{ns}	135.7**	85.3**
Int. (a × b)	6	3,014.4*	3.8*	789.9**	715.7**	0.036^{ns}	2.4^{ns}	248.3^{ns}	0.2^{ns}	0.03*	25.6**	40.9**
Error - b	24	880.2	1.2	134.2	177.0	0.021	9.0	500.5	0.4	0.01	8.2	11.1
CV(%) - a		21.2	33.5	22.4	30.8	32.1	20.0	9.1	14.4	20.4	12.9	19.8
CV(%) - b		16.1	13.8	19.6	24.3	27.6	15.5	9.2	10.6	11.7	12.2	18.7
Planting method (Means) #												
DS		215.9a	8.7a	74.2a	69.7a	0.5a	20.6a	239.3a	5.9a	0.8a	20.1b	15.3b
TP1		167.6b	7.8ab	56.9b	48.9b	0.5a	18.8a	244.9a	5.9a	0.8a	24.8a	18.5a
TP2		169.6b	7.3b	46.0c	45.9b	0.5a	18.8a	246.2a	5.8a	0.8a	25.4a	19.7a

SV = sources of variation; SL = salinity level; PM = planting method; DF = degrees of freedom; CV = coefficient of variation; DS = direct sowing; TP1 = transplanting of seedlings produced with moderate-salinity water (1.5 dS m^{-1}); and TP2 = transplanting of seedlings produced with low-salinity water (0.3 dS m^{-1}). #Means of planting method followed by the same letter are not statistically different from each other.

The main branch length (MBL) decreased linearly as the irrigation water salinity level was increased in the treatments with direct sowing (DS), showing a decrease of 31.45% from the lowest to the highest salinity level (Figure 2A). This inhibition of branch growth is related to the osmotic and ionic effects of salt stress, resulting in disturbances of water relations, ion toxicity, and inhibition of cell elongation (SOUSA et al., 2016). Similar results were reported by Oliveira et al. (2014) for gherkin plants, and by Freitas et al. (2021) when analyzing the morphological responses of peanut (*Arachis hypogaea* L.) grown under salt stress.

Regarding the plants from transplanted seedlings, the polynomial model best fitted the effects of salinity on MBL, regardless of the water used during seedling production (Figure 2A). However, seedlings produced with moderate-salinity water (TP1) had the lowest MBL (143.40 cm) when irrigated with water with electrical conductivity of 2.97 dS m^{-1}, whereas the seedlings produced with low-salinity water (TP2) had the highest MBL (196.97 cm) when irrigated with water with electrical conductivity of 1.79 dS m^{-1}. This result shows that high salt concentrations in the pre-treatment (acclimation) directly affect the necessary growth for salt adaptation, as reported by Kamanga et al. (2020). Ventura et al. (2019) evaluated the responses of cucumber (*Cucumis sativus* L.) to four salinity levels, using the transplanting method and found similar results to those found in the present study. Lima et al. (2015) found contrasting results for eggplant, also using the transplanting method, with plant growth decreasing linearly as the salinity was increased.

The decreasing linear model best fitted the effects of salinity on stem diameter (SD) (Figure 2B) for the planting methos DS and TP2, with decreases of 33.79% and 34.76% from the lowest to the highest salinity level, respectively. This growth inhibition in SD is caused by the toxic effects of salts absorbed by the plants, mainly Na^+ and Cl^-, as well as the osmotic effect, as it causes physiological drought (TAIZ et al., 2017). Lopes et al. (2017) found similar trends when evaluating the growth of two melon varieties subjected to salt stress, with decreases in SD of up to 15.03% and 16.52% for plants of the varieties Gaucho Casca de Carvalho and Hales Best Jumbo, respectively, under the highest salinity level (4.5 dS m^{-1}). Similarly, Oliveira et al. (2014) found a 32.5% decrease in SD of gherkin plants under salt stress (ECw = 5.0 dS m^{-1}).



*, ** - Significant at $p \leq 0.05$ and ≤ 0.01 by the F test, respectively

Figure 2. Main branch length - MBL (A), stem diameter - SD (B), number of branches - NB (C), and shoots dry weight – SDW (D) of watermelon plants irrigated with brackish water in different planting methods. DS = direct sowing; TP1 = transplanting of seedlings produced with moderate-salinity water (1.5 dS m^{-1}), and TP2 = transplanting of seedlings produced with low-salinity water (0.3 dS m^{-1}).

Regarding the TP1 planting method, the polynomial model best fitted effects on SD, with the smallest SD (7.59 mm) found for an electrical conductivity of water (ECw) of 2.97 dS m^{-1}. The increase in SD after this point may be due to plant acclimation, with activation of survival mechanisms. This may promote internal adjustments in tissues and cells, allowing cellular metabolism to continue under these severe salt stress conditions (PANDOLFI et al., 2016).

The number of branches (NB) decreased linearly as the salinity level was increased, regardless of the planting method (Figure 2C), presenting decreases of 41.02% for DS, 37.21% for TP1, and 40.81% for TP2 when comparing the control treatments (0.3 dS m^{-1}) to the highest ECw (4.5 dS m^{-1}). A decrease in NB implies a reduction in the emergence of new leaves, decreasing water consumption through transpiration by the entire plant (AFRIDI et al., 2019). Similar trends were reported by Sousa et al. (2016), who found a 49.6% decrease in NB of mini watermelon plants (cultivar Smile) when increasing the electrical conductivity of the irrigation water. Ribeiro et al. (2020) found a 68.2% decrease in NB of watermelon plants under salt stress.

A quadratic polynomial model best fitted the effects of salinity on shoot dry weight (SDW) for the planting methods DS and TP2 (Figure 2D). DS planting method promoted the lowest SDW (47.54 g) for a ECw of 3.39 dS m^{-1}, whereas TP2 promoted the highest SDW (54.62 g) for a ECw of 1.26 dS m^{-1}. Considering the planting method TP1, a decreasing linear effect was found for SDW, which showed a 46.51% decrease when comparing the lowest and highest salinity levels. Severe stress conditions can result in inactivation of several enzymes, inhibition of protein synthesis, low photosynthetic rate, and visual symptoms of leaf blight (YAN et al., 2018; AFRIDI et al., 2019; SOUSA et al., 2022).

Considering the effects of ECw of 3.0 dS m^{-1} on SDW, decreases of 56.3%, 28.0%, and 10% were found for DS, TP1, and TP2, respectively (Figure 2D). These results indicate that direct sowing (DS) favors the crop establishment in the field, however, with a strong impact at moderate levels of salinity. However, a lower difference in SDW was found between the planting methods TP1 and TP2, indicating that seedlings produced with brackish water do not have significant advantages in acclimating to subsequent salt stress. Results obtained by Lopes et al. (2017) showed decreases of 37.35% and 45.67% in shoot growth for the melon cultivars Gaucho Casca de Carvalho and Hales Best Jumbo, respectively. Similarly, Lima et al. (2015) found a linear decrease of 60% in SDW of eggplant in response to salinity.

The increase in irrigation water salinity caused a linear decrease in leaf gas exchange, regardless of the planting method (Figure 3). Decreases of 62.66%, 17.13%, 14.20%, and 23.65% were found for stomatal conductance (Figure 3A), CO_2 assimilation rate (Figure 3B), internal CO_2 concentration (Figure 3C), and transpiration rate (Figure 3D), respectively, when comparing the treatments with the lowest and highest salinity levels. The inhibition in stomatal conductance may be related to excess salts in the soil solution, causing a reduction in water absorption, promoting stomatal closure, and inhibiting leaf gas exchange (PARIHAR et al., 2015; SOUSA et al., 2018; SILVA et al., 2019). Similar results were found in other studies (RIBEIRO et al., 2020; FREITAS et al., 2021; FREIRE et al., 2021).

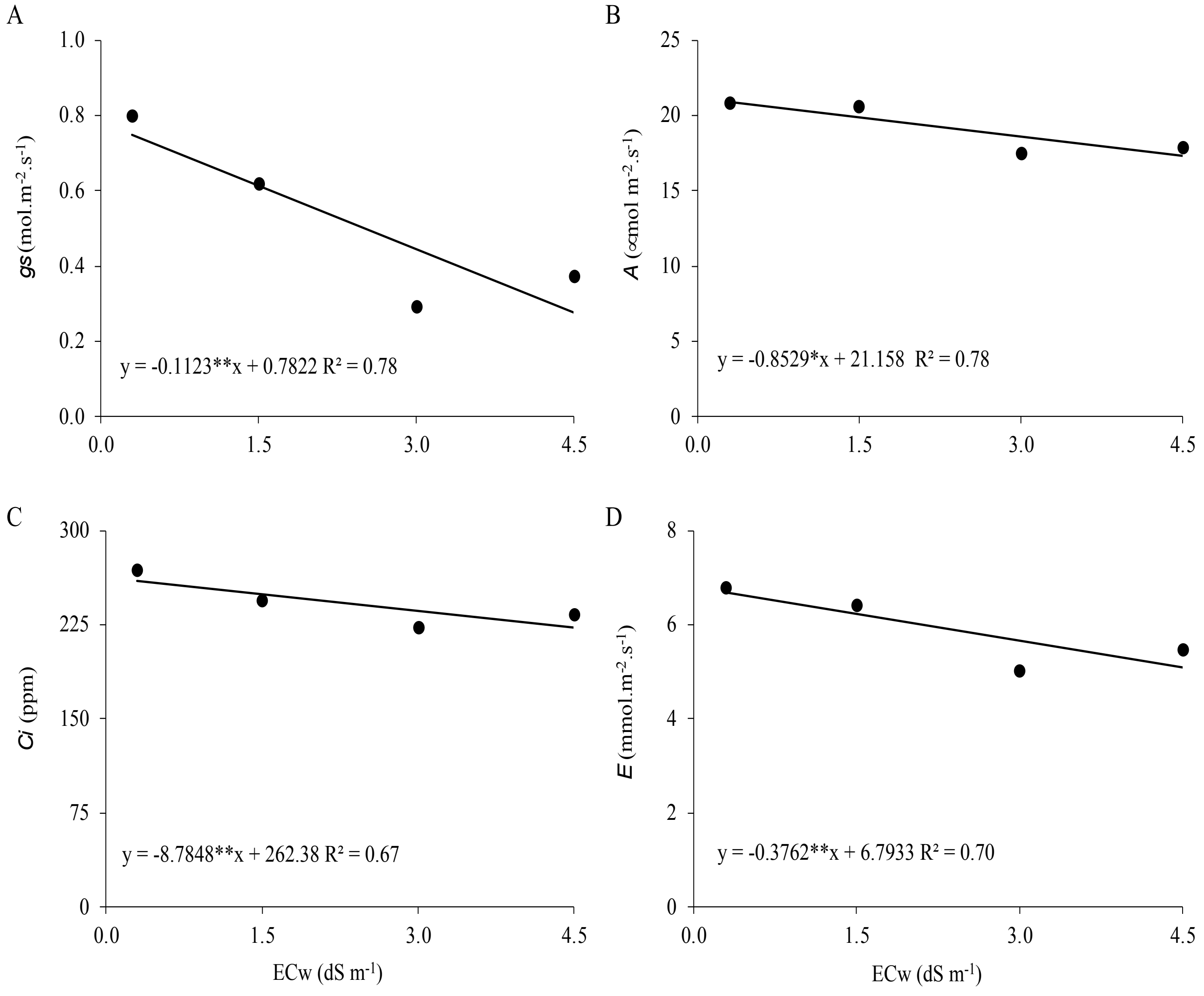


Figure 3. Stomatal conductance - *gs* (A), CO_2 assimilation rate - *A* (B), internal CO_2 concentration - *Ci* (C), and transpiration rate - *E* (D) of watermelon plants as a function of the irrigation water salinity levels.

Sousa et al. (2018) evaluated the physiological dynamics of melon cultivars subjected to salinity and found similar results for the cultivar Goldex. They reported that this melon cultivar presented a linear reduction of 24.82% in stomatal conductance (*gs*) with increasing salinity levels. Similar results were found by Freire et al. (2021) when evaluating leaf gas exchange in fava bean varieties under salinity conditions; the *gs* of the varieties Branquinha and Espirito Santo reduced linearly by 62.5% and 84.8%, respectively, when increasing the electrical conductivity of the irrigation water.

Decreases in CO_2 assimilation rate may be related to inhibition of K^+ absorption under salt stress, especially when Na^+ predominates in the soil solution. These ions are similarly hydrated, thus competing for the same absorption sites on the root cell membrane. Therefore, a decrease in leaf K^+ concentration is often followed by a significant reduction in chlorophyll levels and, consequently, a reduction in photosynthesis (YAN et al., 2018).

The decrease in photosynthetic rate under salt stress may also be related to ionic imbalance and toxicity, mainly due to excessive concentrations of Na^+ and/or Cl^-, as well as reduction of water potential in leaf tissues, which directly impact physiological processes (PARIHAR et al., 2015; AFRIDI et al., 2019). The proportional decreases in *Ci* and *A* caused by salinity (Figure 3) indicate that the decrease in the photosynthetic rate may be related to stomatal effects, restricting both the release of water vapor and the entry of CO_2 into leaf tissues (SILVA et al., 2019; LACERDA et al., 2020).

The polynomial model best fitted the effects of salinity on sodium concentration in leaves for the planting method DS, with the highest concentration (0.85 g kg^{-1}) found for a ECw of 2.78 dS m^{-1}. According to Ekbic et al. (2017), progressive levels of salt stress increase Na^+ accumulation in leaves of watermelon plants. However, increasing the calcium concentration can reduce the sodium absorption and accumulation in leaf tissues (PRADO, 2020).

Considering the planting methods TP1 and TP2, sodium contents increased linearly as the irrigation water salinity was increased. Increases of 6.67% and 55.38% were found for TP1 and TP2, respectively, when comparing the treatments with the lowest and highest salinity levels. The increase in Na^+ concentration in leaf tissues is one of the main effects of salt stress, reflecting the absorption and transport of this ion through the xylem (EKBIC et al., 2017; BEZERRA et al., 2021; SILVA et al., 2021).

According to Pandolfi et al. (2016), acclimated plants have a greater capacity for vacuolar sequestration of Na^+ in the leaves and, therefore, can accumulate higher amounts of sodium in the shoots without having any harmful effect on leaf photochemistry. However, this Na^+ sequestration requires the accumulation of K^+ and/or organic solutes in the cytosol to balance the differential osmotic pressure generated by the excess Na^+ in the vacuole (KAMANGA et al., 2020).

The effects of salinity on chloride concentration in leaves (Figure 4B) fitted to a quadratic polynomial model for the planting methods DS and TP1, with the highest concentrations found for ECw of 1.80 and 2.91 dS m^{-1}, respectively. In general, salt stress causes osmotic stress, disruption of ion homeostasis in the cell, and accumulation of Na^+ and Cl^- in the cytoplasm (TAIZ et al., 2017). However, NO_3^- and SO_4^{2-} can inhibit the absorption of Cl^- by competitiveness (PRADO, 2020). Similar trends were found by Sousa et al. (2012) for jatropha plants, with the highest Cl^- concentration found at a ECw of 1.9 dS m^{-1}, through the regression model.

Considering the planting method TP2, chloride concentrations increased linearly as the irrigation water salinity level was increased (Figure 4B), with a total increase of 21.25% for plants subjected to ECw of 4.5 dS m^{-1}. This result may be related to the presence of Cl^- in the salts used for preparing the irrigation water and its high mobility in the xylem, as it is transported to the shoots in its anionic form (PRADO, 2020). Similar results were found for pumpkin (SILVA et al., 2013) and cherry tomato plants (SANTOS et al., 2017).

Calcium concentrations in leaves increased linearly as the irrigation water salinity level was increased, regardless of the planting method. The highest increase found was 321.37%, 120.61%, and 60.93% for DS, TP1, and TP2, respectively, when comparing the lowest and the highest salinity levels. Similar results were found by Sousa et al. (2012) when evaluating nutrient concentration in leaves of jatropha plants grown under salt stress; they found a linear increase in calcium concentration as the electrical conductivity of the irrigation water was increased. Similarly, Ekbic et al. (2017) studied salt tolerance in watermelon accessions and found increases in Ca levels as the salt stress increased.

According to Bezerra et al. (2021), increases in calcium concentration in leaves of plants irrigated with saline water can also be associated with a higher availability of this nutrient, as the irrigation water depths leaches part of the salts from the root environment, and calcium is more strongly adsorbed to soil colloids than sodium, mainly due to the difference in valences between these elements. Furthermore, calcium was an important component of the irrigation water used in the present study, which explains its accumulation in the leaf tissues of watermelon plants under high salinity treatments.

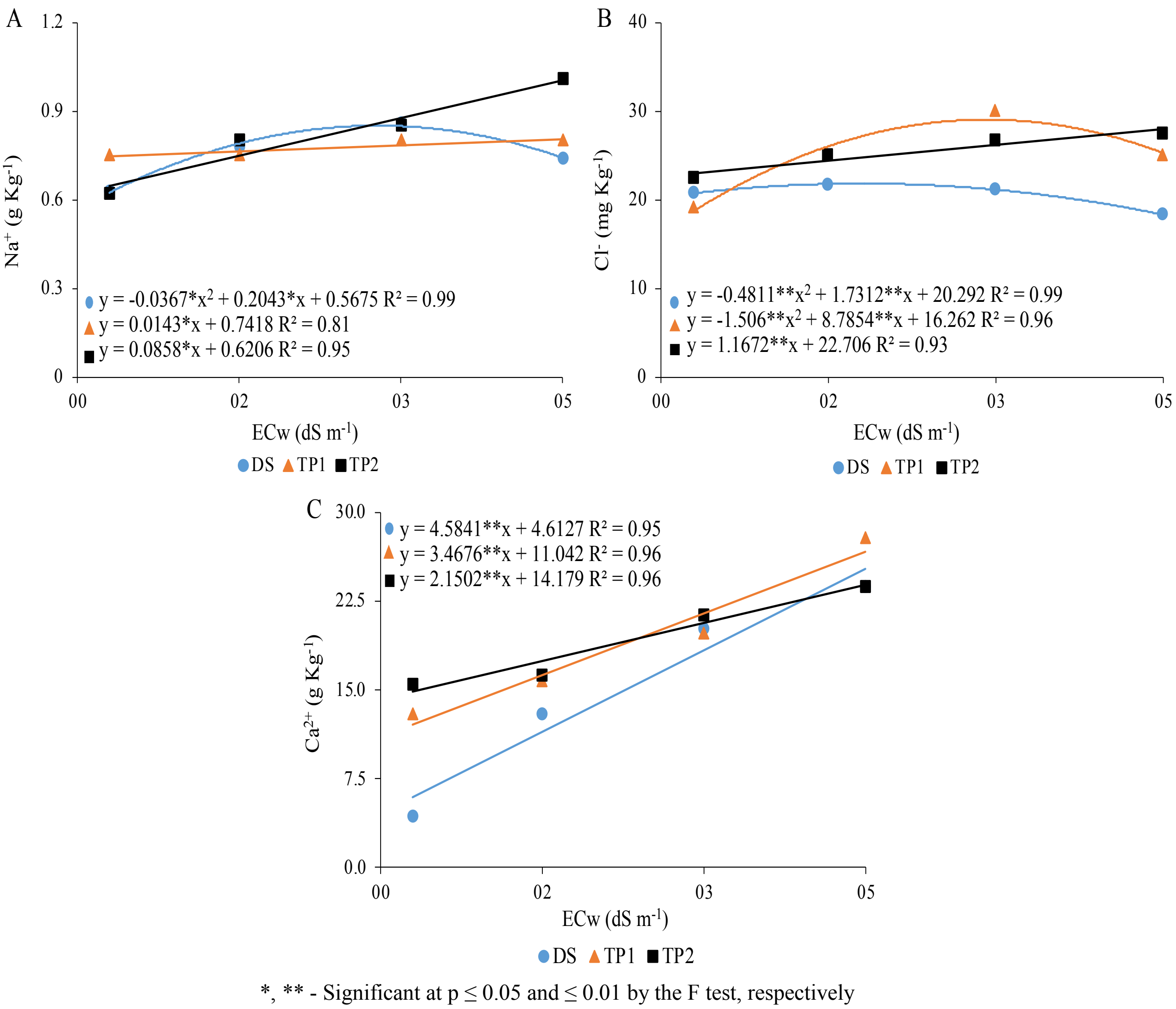


Figure 4. Sodium (A), chloride (B), and calcium (C) concentrations in leaves of watermelon plants irrigated with brackish water in different planting methods. DS = direct sowing; TP1 = transplanting of seedlings produced with moderate-salinity water (1.5 dS m^{-1}), and TP2 = transplanting of seedlings produced with low-salinity water (0.3 dS m^{-1}).

CONCLUSIONS

The use of watermelon seedlings produced with moderate-salinity water (1.5 dS m^{-1}) does not result in a greater in salt tolerance during the vegetative growth stage.

The use of brackish water caused negative effects on physiological processes of watermelon crops.

Leaf Na^+, Cl^-, and Ca^{2+} concentrations increase as the irrigation water salinity level increases, regardless of the planting method used. However, plants from seedlings produced with moderate-salinity water (1.5 dS m^{-1}) and low-salinity low (0.3 dS m^{-1}) have higher Na^+ and Cl^- concentrations when subject to high salinity levels.

Direct sowing provided better performance for almost all growth variables, compared to the seedling transplanting methods used, and it was more evident under low salinity levels.

REFERENCES

AFRIDI, M. S. et al. Induction of tolerance to salinity in wheat genotypes by plant growth promoting endophytes: Involvement of ACC deaminase and antioxidant enzymes. **Plant Physiology and Biochemistry**, 139: 569-577, 2019.

ALLEN, R. G. et al. **Crop evapotranspiration-guidelines for computing crop water requirements**. Roma: FAO, 1998. 300 p. (FAO - Irrigation and Drainage Paper, 56).

BEZERRA, M. A. F. et al. Calcium in the mineral nutrition of yellow passion fruit cultivated in lined pits and with saline water. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 25: 256-263, 2021.

COSTA, A. R.; MEDEIROS, J. F. D. Nitrogen, phosphorus and potassium accumulation in watermelon cultivars irrigated with saline water. **Engenharia Agrícola**, 38: 343-350, 2018.

EKBIC, E. et al. Assessment of watermelon accessions for salt tolerance using stress tolerance índices. **Ciência e Agrotecnologia**, 41: 616-625, 2017.

FAOSTAT. Food and Agriculture Organization of the United Nations (FAO). **Crops and livestock products – Watermelons**. 2021. Disponível em: <http://www.fao.org/faostat/en/#data/QC/visualize>. Acesso em: 1 jun. 2023.

FREIRE, M. H. C. et al. Trocas gasosas de variedades de fava sob condições de salinidade da água de irrigação. **Agrarian**, 14: 61-70, 2021.

FREITAS, A. G. S. et al. Morfofisiologia da cultura do amendoim cultivado sob estresse salino e nutricional. **Revista Brasileira de Agricultura Irrigada**, 15: 48-57, 2021.

JANDA, T. et al. Salt acclimation processes in wheat. **Plant Physiology and Biochemistry**, 101: 68-75, 2016.

KAMANGA, R. M. et al. Salinity acclimation ameliorates salt stress in tomato (*Solanum lycopersicum* L.) seedlings by triggering a cascade of physiological processes in the leaves. **Scientia Horticulturae**, 270: 1-9, 2020.

LACERDA, C. F. et al. Morphophysiological responses and mechanisms of salt tolerance in four ornamental perennial species under tropical climate. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 24: 656-663, 2020.

LIMA NETO, I. S. et al. Preparo do Solo e Plantio. In: NICK, C; BORÉM, A. (Eds.). **Melancia: do plantio à colheita**. Viçosa, MG: Ed. UFV, 2019. v. 1, cap. 6, p. 85-100.

LIMA, L. A. et al. Tolerância da berinjela à salinidade da água de irrigação. **Revista agro@mbiente on-line**, 9: 27-34, 2015.

LOPES, M. Â. C. et al. Água salina e substratos no crescimento inicial do meloeiro. **Irriga**, 22: 469-484, 2017.

MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. Metodologia para análise de elementos em material vegetal. In: MALAVOLTA, E.; VITTI, G. C.; OLIVEIRA, S. A. (Eds.). **Avaliação do estado nutricional das plantas: princípios e aplicações**. Piracicaba, SP: Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1997. v. 2, cap. 6, p. 231-308.

MAROUELLI, W. A.; BRAGA, M. B. **Irrigação na produção de mudas de hortaliças**. Uberlândia, MG: Campo & Negócios Hortifruti, 2016. 4 p.

MENEGHETTI, A. D. **Manual de procedimentos de amostragem e análise química de plantas, solo e fertilizantes**. Curitiba, PR: EDUTFPR, 2018. 252 p.

MIRANDA, F. R.; OLIVEIRA, J. J. G.; SOUZA, F. Evapotranspiração máxima e coeficientes de cultivo para a cultura da melancia irrigada por gotejamento. **Revista Ciência Agronômica**, 35: 36-43, 2004.

NATALE, W. et al. Mineral nutrition evolution in the formation of fruit tree rootstocks and seedlings. **Revista Brasileira de Fruticultura**, 40: e-133, 2018.

OLIVEIRA, F. A. et al. Tolerância do maxixeiro, cultivado em vasos, à salinidade da água de irrigação. **Revista Ceres**, 61: 147-154, 2014.

PANDOLFI, C. et al. Acclimation improves salt stress tolerance in Zea mays plants. **Journal of Plant Physiology**, 201: 1-8, 2016.

PARIHAR, P. et al. Effect of salinity stress on plants and its tolerance strategies: a review. **Environmental Science and Pollution Research**, 22: 4056-4075, 2015.

PRADO, R. M. **Nutrição de Plantas**. 2. ed. São Paulo, SP: Editora UNESP, 2020. 426 p.

RHOADES, J. D.; KANDIAH, A.; MASHALI, A. M. **Uso de águas salinas para produção agrícola**. Campina Grande, PB: UFPB, 2000. 117 p. (Estudos FAO - Irrigação e Drenagem, 48).

RIBEIRO, J. E. S. et al. *Citrullus lanatus* morphophysiological responses to the combination of salicylic acid and salinity stress. **Revista Brasileira de Ciências Agrárias**, 15: e6638, 2020.

SANTOS, A. N. et al. Concentração de nutrientes em tomate cereja sob manejos de aplicação da solução nutritiva com água salobra. **Revista Ciência Agronômica**, 48: 576-585, 2017.

SILVA, F. A. S.; AZEVEDO, C. A. V. The Assistat Software Version 7.7 and its use in the analysis of experimental data. **Africal Journal of Agriculture Research**, 11: 3733-3740, 2016.

SILVA, J. L. A. et al. Nutritional status of Galia melon plants irrigated with saline water in different soils. **Dyna**, 88: 79-86, 2021.

SILVA, M. V. T. et al. Diagnose foliar da abóbora submetida a diferentes níveis de salinidade e doses crescentes de nitrogênio. **Agropecuária Científica no Semiárido**, 9: 118-125, 2013.

SILVA, S. S. et al. Gas exchanges and production of watermelon plant under salinity management and nitrogen fertilization. **Pesquisa Agropecuária Tropical**, 49: e54822, 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.

SOUSA, G. G. et al. Saline water and nitrogen fertilization on leaf composition and yield of corn. **Revista Caatinga**, 35: 191-198, 2022.

SOUSA, V. F. O. et al. Physiological behavior of melon cultivars submitted to soil salinity. **Pesquisa Agropecuária Tropical**, 48: 271-279, 2018.

TAIZ, L. et al. **Fisiologia e desenvolvimento vegetal**. 6. ed. Porto Alegre, RS: Artmed, 2017. 858 p.

USDA - United States Department of Agriculture. **Keys to Soil Taxonomy**. 13. Ed. Washington, DC: Natural Resources Conservation Service, 2022. 401 p.

YAN, Y. Q. et al. Effect of different rootstocks on the salt stress tolerance in watermelon seedlings. **Horticultural Plant Journal**, 4: 239-249, 2018.

VENTURA, K. M. et al. Tolerância de híbridos de pepino à níveis de salinidade em ambiente protegido. **Revista Brasileira de Agricultura Irrigada**, 13: 3783-3791, 2019.