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Morphophysiology of mini watermelon in hydroponic cultivation using reject brine and substrates[1]

Morfofisiologia da mini melancieira em cultivo hidropônico usando rejeito salino e substratos

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HIGHLIGHTS:
Growth and leaf area of mini watermelon in hydroponic cultivation are reduced at electrical conductivity above 4.00 dS m⁻¹.
Electrical conductivity of up to 6.90 dS m⁻¹ does not reduce the net photosynthesis of mini watermelon in hydroponic cultivation.
Coconut fiber is the best hydroponic substrate for mini watermelon.

ABSTRACT: The objective of the study was to evaluate the growth and physiological aspects of the 'Sugar Baby' mini watermelon grown in a hydroponic system with different substrates and mixtures of reject brine in the preparation of the nutrient solution. For this purpose, the experiment was carried out in a plastic greenhouse, using a randomized block design, in a 5 x 4 factorial scheme, corresponding to the combination of five mixtures of reject brine (electrical conductivity - EC = 9.50 dS m^{-1}) and tap water (EC = 0.54 dS m^{-1}) and four types of substrates (coconut fiber, sand, 70% sand + 30% rice husk and 40% sand + 60% rice husk), distributed in four replicates. Using the mixture of reject brine and tap water with EC above 4.00 dS m^{-1} to prepare the nutrient solution of mini watermelon plants markedly reduced their growth. Increments in carboxylation efficiency and activity in the electron transport chain act as tolerance mechanisms to compensate for the net photosynthesis of mini watermelon under salt stress. Coconut fiber promoted the best growth and photosynthetic activity for mini watermelon plants, while the substrate with 100% washed sand led to the lowest performance.

Key words: *Citrullus lanatus*, salt stress, chlorophyll fluorescence, gas exchange

RESUMO: Objetivou-se avaliar o crescimento e os aspectos fisiológicos da mini melancieira 'Sugar Baby' em sistema hidropônico com diferentes substratos e misturas de rejeito salino no preparo da solução nutritiva. Para isso, o experimento foi desenvolvido em estufa plástica, usando delineamento experimental de blocos casualizados, em esquema fatorial 5 x 4, correspondentes à combinação de cinco misturas de rejeito salino (condutividade elétrica – CE = 9,50 dS m^{-1}) e água de torneira (CE = 0,54 dS m^{-1}) e quatro tipos de substratos (fibra de coco, areia lavada, 70% areia lavada + 30% casca de arroz e 40% areia lavada + 60% casca de arroz), com quatro repetições. O uso da mistura de rejeito salino e água de torneira com CE acima de 4,00 dS m^{-1} no preparo da solução nutritiva da mini melancieira reduziu de forma acentuada o crescimento das plantas. O aumento da eficiência de carboxilação e da atividade na cadeia transportadora de elétrons, atuam como mecanismos de tolerância para compensar a fotossíntese líquida da mini melancieira sob estresse salino. A fibra de coco proporcionou o melhor crescimento e atividade fotossintética da mini melancieira, e o substrato com 100% areia lavada proporcionou o menor desempenho.

Palavras-chave: *Citrullus lanatus*, estresse salino, fluorescência da clorofila, trocas gasosas

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Introduction

Brazil is a privileged country with regard to the availability of low-salinity water, since it has 12% of the total found in the world. However, its distribution is quite uneven, in the comparison between the regions of the country. In order to increase water availability to the northeast region, one of the strategies is to desalinate brackish groundwater, which can be a concrete tool of regional development in the Brazilian semi-arid region.

The predominant desalination method is the process of reverse osmosis, which is mainly due to the simplicity and robustness of the equipment and low costs for installation and operation, associated with the capacity to treat small or moderate volumes of raw water. However, a negative point of reverse osmosis desalination is the fact that, in order to generate drinking water, this process necessarily generates a highly brackish water, called brine or reject brine (Antas et al., 2019).

One of the alternatives for disposing of reject brine would be its use as a component of nutrient solutions in hydroponic cultivation in protected environments. Hydroponic cultivation in inert substrates can increase water and nutrient use efficiency, and the absence of matric potential minimizes salinity effects on plants (Oliveira et al., 2016; 2018). However, salt stress in these systems also reduces growth, gas exchange and photochemical efficiency of plants (Sá et al., 2018).

Watermelon (*Citrullus lanatus* [Thumb.] Matsumura & Nakai) is among the crops that stand out in hydroponic cultivation, mainly cultivars called ice box or mini watermelons, with fruits weighing between 1 and 3 kg, which can be easily stored and refrigerated (Campagnol et al., 2016; Marques et al., 2016). The objective of this study was to evaluate the growth and physiological aspects of 'Sugar Baby' mini watermelon cultivated in hydroponic system with different substrates and mixtures of reject brine in the preparation of the nutrient solution.

Material and Methods

The experiment was carried out in a plastic greenhouse of the Department of Environmental and Technological Sciences of the Federal Rural University of the Semi-Arid Region (UFERSA), in Mossoró, RN, Brazil, from August to October 2018. The geographical coordinates of the area are 5° 11' S latitude, 37° 20' W longitude, and 18 m altitude.

The study was carried out in a plastic greenhouse of 126 m^2, with ceiling height of 4.0 m, metallic structure, covered with transparent plastic material and 50% shade net walls. During the experiment, the observed maximum and minimum values of temperature and air relative humidity were 39.2 and 20.4 °C and 86 and 22%, respectively.

The experimental design used was randomized blocks, in a 5 x 4 factorial scheme, with four replicates, and the experimental unit was represented by two plants.

The treatments were formed by combining five mixtures of reject brine - RB (ECw = 9.50 dS m^{-1}) and tap water - TW (EC = 0.54 dS m^{-1}) for the irrigation of mini watermelon plants (M_1 - 100% TW with 0.54 dS m^{-1}; M_2 - 85% TW + 15% RB with 2.40 dS m^{-1}; M_3 - 70% TW + 30% RB with 4.00 dS m^{-1}; M_4 - 55% TW + 45% RB with 5.48 dS m^{-1}; M_5 - 40% TW + 60% RB with 6.90 dS m^{-1}), in an open hydroponic system, and four types of growing substrates (S_1 - Coconut fiber, S_2 - Washed sand, S_3 - 70% Washed sand + 30% Rice husk and S_4 - 40% Washed sand + 60% Rice husk).

The cultivar used was 'Sugar Baby', characterized by having rounded fruits, with dark green rind and bright red flesh, measuring between 20 and 25 cm in diameter, weighing between 1 and 3 kg, with few seeds, being ideal for areas with limited space.

Mini watermelon plants were cultivated in plastic pots with capacity for 6 dm^3 of substrate, according to treatment, in an open hydroponic system. Sowing was performed by planting three seeds per pot and, after emergence, thinning was performed, leaving one plant per pot. Plants were trained on a trellis system, with 2.0 m height, with 1.00 m spacing between rows. Watermelon plants were fixed to the vertical trellis system using raffia ribbon, and the excess lateral shoots were eliminated by pruning up to the 9th branch, leaving the other shoots with five leaves, in addition to the elimination of the apical bud, when the plants reached 2 m height.

From sowing until the tenth day, the plants were irrigated with tap water (ECw = 0.54 dS m^{-1}) and, from then on, the saline nutrient solutions, prepared according to the predetermined proportions, began to be applied. Reject brine was obtained in the Jurema Settlement, located by the side of the RN – 012 highway, which connects Mossoró to the municipality of Tibau, and had EC of 9.50 dSm^{-1}. The physicochemical characteristics of reject brine and tap water (TW) are presented in Table 1.

Irrigations were performed twice a day, in the early morning and in the late afternoon, applying a volume corresponding to the actual evapotranspiration of the crop, measured by drainage lysimeter in additional plots, corresponding to each treatment. The water depth applied in the treatments was calculated by the difference between the irrigation depth and the leached depth in the pots of the additional plots. These applications were performed using a drip irrigation system, composed of 16-mm-diameter hoses and pressure-compensating drippers with flow rate of 1.4 L h^{-1}.

An independent irrigation system was used in each treatment, formed by a self-venting centrifugal motor pump, driven by single-phase motor, 210 V voltage, 60 Hz frequency, normally used in a washing machine, installed in a reservoir with capacity for 50 L.

Table 1. Physicochemical characterization of the water sources used in the experiment

Water sources	Attributes									
	pH	EC (dS m^{-1})	K^+	Na^+	Mg^{2+}	Ca^{2+}	Cl^-	CO_3^{2-}	HCO_3^-	SAR $(mmol\ L^{-1})^{0.5}$
			($mmol_c\ L^{-1}$)							
Tap water	7.57	0.54	0.31	3.79	1.20	0.83	2.40	0.60	3.20	3.76
Reject brine	7.10	9.50	0.83	54.13	24.20	37.80	116.00	0.00	3.40	9.70

EC - Electrical conductivity; SAR - Sodium adsorption ratio $[Na/(Ca+Mg/2)]^{0.5}$

The nutrient solution used was adapted from that proposed by Marques et al. (2014) and had the following concentrations (mmol L^{-1}): 12.8 of NO_3^-, 1.4 of $H_2PO_4^-$, 2.0 of SO_4^{2-}, 0.8 of NH_4^+, 6.0 of K^+, 4.0 of Ca^{2+} and 1.7 of Mg^{2+}. Micronutrients were supplied by the commercial compound Rexolin BRA, composed of 11.68% potassium oxide (K_2O), 1.28% sulfur (S), 2.1% boron (B), 0.36% copper (Cu), 2.65% iron (Fe), 2.48% manganese (Mn), 0.036% molybdenum (Mo) and 3.38% zinc (Zn), following the manufacturer's recommendation (2 g L^{-1}). The nutrient solution had electrical conductivity of 1.1 dS m^{-1}; therefore, after preparation, the solutions showed the following electrical conductivities: M_1 with 1.64 dS m^{-1}, M_2 with 3.50 dS m^{-1}; M_3 with 5.10 dS m^{-1}; M_4 with 6.58 dS m^{-1} and M_5 with 8.00 dS m^{-1}. The pH of the nutrient solution was calibrated to 6.5 using acetic acid and sodium hydroxide.

Growth analysis was performed at 25 days after sowing. Plant height (PH) was measured from the soil up to the apical meristem insertion, and data were expressed in cm. Stem diameter (SD) was determined at 1 cm height from the soil, with a digital caliper, and the values were expressed in mm. Number of leaves (NL) was determined by simply counting the leaves of each plant with length equal to or greater than 5 cm. Leaf area (LA) was determined using data of longitudinal and diagonal leaf lengths, with correction factor of 0.7, proposed by Silva Júnior et al. (2015).

Physiological analyses were performed during the vegetative stage of the plants, at 25 days after sowing. Gas exchange was measured between 6 and 9 a.m., in fully expanded leaves located in the upper third of each plant, using a portable infrared carbon dioxide analyzer (IRGA), LCPro+ Portable Photosynthesis System® model (ADC BioScientific Limited, UK), with temperature control at 25 °C, irradiation of 1200 μmol photons m^{-2} s^{-1} and airflow of 200 mL min^{-1}. The obtained variables were net photosynthesis rate (A_N) (μmol m^{-2} s^{-1}), transpiration (E) (mmol H_2O^{-2} s^{-1}), stomatal conductance (gs) (mol H_2O m^{-2} s^{-1}) and internal CO_2 concentration (Ci) (μmol m^{-2} s^{-1}). These data were then used to quantify the instantaneous water use efficiency (WUEi) (A/E) [(μmol m^{-2} s^{-1})(mol H_2O m^{-2} s^{-1})$^{-1}$] and carboxylation efficiency (A_N/Ci) (Silva et al., 2014).

Chlorophyll a fluorescence was determined with a pulse-modulated fluorometer, OS5p model from Opti science. The Fv/Fm protocol was used for evaluations under dark conditions. Under these conditions, the following fluorescence induction variables were estimated: initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv = Fm-Fo) and maximum quantum efficiency of PSII (Fv/Fm) (Genty et al., 1989).

With the same device, the Yield protocol was used to obtain the readings under light conditions, applying an actinic light source with multi-flash saturating pulse, coupled to a photosynthetically active radiation determination clip (PAR-Clip) to estimate the following variables: initial fluorescence before the saturation pulse (F'), maximum fluorescence after adaptation to saturated light (Fm'), electron transport rate (ETR) and quantum efficiency of photosystem II (PS II) (Y_{II}). These data were used to determine: minimum fluorescence of the illuminated plant tissue (Fo') (Oxborough & Baker, 1997); photochemical quenching coefficient by the lake model (qL) (Kramer et al., 2004); quantum yield of regulated photochemical quenching (Y_{NPQ}) (Kramer et al., 2004); quantum yield of non-regulated photochemical quenching (Y_{NO}) (Kramer et al., 2004).

The data obtained were subjected to analysis of variance ($p \leq 0.05$) and Tukey test ($p \leq 0.05$), using the statistical program Sisvar 5.6 (Ferreira, 2014).

Results and Discussion

There was no significant effect ($p > 0.05$) of the interaction between water mixtures x substrates for the variables plant height (PH), stem diameter (SD), number of leaves (NL) and leaf area (LA). There was a significant simple effect ($p \leq 0.001$) of the water mixtures used in the composition of the nutrient solution and the types of substrates for the variables PH, SD, NL and LA, when evaluated at 25 days after sowing (Table 2).

PH, SD, NL and LA were reduced by 32.63, 1.85, 17.80 and 42.68%, respectively, when mini watermelon plants were cultivated under M_5 (40% TW + 60% RB) in the nutrient solution, compared to the control (M_1 = 100% TW) (Table 2). In the growth in PH, SD, NL and LA, there was no significant difference between plants irrigated with M_1 (100% TW) and M_2 (85% TW + 15% RB).

Salinization of the substrate causes reduction in its osmotic potential and consequently in its water potential, limiting the water absorption by the plant. This effect prevents cell expansion, since the osmotic potential of the cell tends to match the water potential of the substrate. In this context, with the osmotic restriction, limitation in cell expansion and reduction in growth and leaf area are apparent symptoms (Sá et al., 2013; Gupta & Huang, 2014). The main effect of salinity on plant

Table 2. Probability of F test and means comparison test for plant height (PH), stem diameter (SD), number of leaves (NL) and leaf area (LA) of mini watermelon plants in the vegetative stage subjected to different water mixtures used in the preparation of nutrient solution and types of substrate in hydroponic system, at 25 days after sowing

Source of variation	Probability of F test			
	PH	SD	NL	LA
Block	0.0781	0.3690	0.5017	0.2756
Water mixtures	0.0000	0.0020	0.0000	0.0000
Substrates	0.0000	0.0000	0.0000	0.0000
Water mixtures x Substrates	0.0878	0.0743	0.6634	0.0648
CV (%)	21.97	8.71	14.74	19.28
Water mixtures (M)	**Means**			
	(cm)	(mm)	(und)	(m^2)
M_1 - 100% TW (control)	47.31 a	4.001 ab	7.75 a	0.0403 a
M_2 - 85% TW + 15% RB	43.62 a	4.134 a	7.56 a	0.0350 a
M_3 - 70% TW + 30% RB	34.87 b	3.681 b	6.50 b	0.0289 b
M_4 - 55% TW + 45% RB	33.50 b	3.740 b	6.18 b	0.0232 b
M_5 - 40% TW + 60% RB	31.87 b	3.927 ab	6.37 b	0.0231 b
Substrates (S)	(cm)	(mm)	(und)	(m^2)
S_1 - Coconut fiber	71.15 a	4.783 a	9.70 a	0.0585 a
S_2 - 100% Sand (S)	18.65 c	3.296 c	5.05 c	0.0138 c
S_3 - 70% S + 30% RH	30.75 b	3.773 b	6.45 b	0.0246 b
S_4 - 40% S + 60% RH	32.40 b	3.744 b	6.30 b	0.0236 b

Salinities of the water mixtures, in dS m^{-1}: M_1 - 0.54; M_2 - 2.40; M_3 - 4.00; M_4 - 5.48; M_5 - 6.90. CV - Coefficient of variation; TW - Tap water; RB - Reject brine; RH - Rice husk; Means followed by the same letter in the column do not differ from each other at $p \leq 0.05$ by Tukey test growth occurs on the reduction of leaf area, which decreases the area destined for photosynthesis, limiting the production of photoassimilates by the plant and reducing its production capacity (Paulus et al., 2012).

In recent studies with the mini watermelon cv. Smile, Sousa et al. (2016) verified that the variables plant height and number of leaves of the main branch were affected by irrigation water salinity. According to these authors, plant height and number of leaves of the main branch were reduced by 19.0 and 20.2%, respectively, in plants subjected to 5.0 dS m^{-1} in irrigation water.

Coconut fiber outperformed the other types of substrates with respect to all variables analyzed, while the substrate with 100% sand led to the lowest growth. The differences between coconut fiber and 100% sand substrates were 73.79, 31.09, 47.94 and 76.41%, respectively, for the variables PH, SD, NL and LA. According to Sumida et al. (2014), the substrate performs direct functions in the mechanical maintenance of the root system, plant stability, supply of water, nutrients and oxygen, in addition to the transport of carbon dioxide between roots and external air; therefore, it performs more than the function of support to plants. The good performance observed with the cultivation in coconut fiber is linked to its structure and physicochemical properties, showing high water retention capacity, aeration of the growing medium and stimulus to rooting.

There was no significant effect ($p > 0.05$) of the interaction between water mixtures and substrates on the gas exchange of mini watermelon. However, there were simple effects of water mixtures on transpiration ($p \leq 0.001$), internal CO_2 concentration ($p \leq 0.001$), instantaneous water use efficiency ($p \leq 0.01$) and carboxylation efficiency ($p \leq 0.01$) and of substrates on stomatal conductance ($p \leq 0.001$), net photosynthesis ($p \leq 0.001$), transpiration ($p \leq 0.001$) and carboxylation efficiency ($p \leq 0.01$) (Table 3).

The use of the M_5 mixture (40% TW + 60% RB) in the nutrient solution of mini watermelon plants caused reductions of up to 14.76 and 16.47% in Ci and WUEi, respectively, and increments of up to 23.44 and 22.01% in E and A_N/Ci, respectively, compared to the control, without causing damage to stomatal activity and net photosynthesis (Table 3).

Plants that received reject brine increased their transpiration rate and, consequently, their water consumption, thus reducing WUEi (Table 3). This physiological response did not affect net photosynthesis, which was compensated at the highest salinity levels by the increase in the activity of Ribulose-1,5-bisphosphate Carboxylase-Oxygenase (RuBisCO), since there was an increase in A_N/Ci (Table 3). Moreover, despite the decreases in Ci, there was no lack of CO_2 for the RuBisCO operation, so the photosynthetic activity of mini watermelon was maintained.

Oliveira et al. (2016), studying the cv. Crimson Sweet in an open hydroponic cultivation, found linear reductions in the variables gs, Ci and E as a function of the increase in nutrient concentrations in the nutrient solution. Silva et al. (2019) evaluated the gas exchange and production of ‘Sugar Baby’ watermelon cultivated in soil under salinity management and nitrogen fertilization and found that irrigation using water with electrical conductivity of 3.2 dS m^{-1} in the vegetative, flowering and fruit maturation stages reduces stomatal opening, transpiration and net photosynthesis of mini watermelon plants.

Table 3. Probability of F test and means comparison tests for stomatal conductance (gs), net photosynthesis (A_N), internal CO_2 concentration (Ci), transpiration (E), instantaneous water use efficiency (WUEi) and carboxylation efficiency (A_N/Ci) of mini watermelon plants in the vegetative stage subjected to different water mixtures used in the preparation of nutrient solution and types of substrate in hydroponic system, at 25 days after sowing

Source of variation	Probability of F test					
	gs	A_N	Ci	E	WUEi	A_N/Ci
Block	0.0003	0.0058	0.7631	0.0310	0.3027	0.1259
Water mixtures	0.2429	0.3287	0.0000	0.0000	0.0000	0.0056
Substrates	0.0000	0.0005	0.0574	0.0000	0.3321	0.0077
Water mixtures x Substrates	0.8992	0.4849	0.3805	0.9379	0.6403	0.2021
CV (%)	13.54	11.08	7.37	9.00	8.89	15.24
	Means					
Water mixtures (M)						
M_1 - 100% TW (control)	0.246 a	20.13 a	193.1 a	4.48 d	4.365 a	0.1013 b
M_2 - 85% TW + 15% RB	0.222 a	18.63 a	179.1 b	5.10 bc	3.634 b	0.1051 b
M_3 - 70% TW + 30% RB	0.238 a	19.97 a	182.1 ab	4.79 cd	4.177 a	0.1105 ab
M_4 - 55% TW + 45% RB	0.232 a	19.40 a	173.0 bc	5.70 ab	3.397 b	0.1131 ab
M_5 - 40% TW + 60% RB	0.227 a	19.50 a	164.6 c	5.53 a	3.646 b	0.1236 a
Substrates (S)						
S_1 - Coconut fiber	0.199 b	17.64 b	175.8 a	4.67 b	3.821 a	0.1006 b
S_2 - 100% Sand (S)	0.253 a	19.96 a	185.5 a	5.39 a	3.737 a	0.1083 ab
S_3 - 70% S + 30% RH	0.241 a	20.41 a	175.5 a	5.26 a	3.737 a	0.1179 a
S_4 - 40% S + 60% RH	0.238 a	20.07 a	176.5 a	5.17 a	3.898 a	0.1160 a

Salinities of the water mixtures, in dS m^{-1}: M_1 - 0.54; M_2 - 2.40; M_3 - 4.00; M_4 - 5.48; M_5 - 6.90; CV - Coefficient of variation; TW - Tap water; RB - Reject brine; RH - Rice husk; Means followed by the same letter in the column do not differ from each other at $p \leq 0.05$ by Tukey test; gs, in mol of H_2O m^{-2} s^{-1}; A_N, in μmol m^{-2} s^{-1}; Ci, in μmol mol^{-1}; E, in mol of H_2O m^{-2} s^{-1}; WUEi, in (μmol m^{-2} s^{-1})(mol H_2O m^{-2} s^{-1})$^{-1}$

In situations of osmotic stress caused by excess salts in irrigation water, one of the first reactions of plants is the closure of stomata to avoid water losses through transpiration (Silva et al., 2014; Sousa et al., 2019). According to Larcher (2004), this response usually occurs before the inhibition of photosynthesis and restricts the availability of CO_2 at assimilation sites in the chloroplast.

Stomatal closure has as consequence reduction in the photosynthetic rate, being one of the main causes of decrease in the growth and yield of plants, since biomass accumulation depends on the production of photoassimilates. However, the mini watermelon plants were able to overcome the effects of osmotic restriction, maintaining stomatal activity, and increasing transpiration and water consumption, to regulate CO_2 carboxylation.

Mini watermelon plants, when cultivated in coconut fiber substrate, had the lowest rates of gs, A_N, E and A_N/Ci compared to the other types of substrates (Table 3), although greater growth, including in leaf area, was observed (Table 2). Thus, the higher activity of gas exchange observed in plants grown in the substrate with sand and sand + rice husk may be related to higher efficiency of CO_2 carboxylation, possibly due to the smaller photosynthetically active area of these plants.

There was no significant effect ($p > 0.05$) of the interaction between water mixtures and substrates on the initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv) and maximum quantum efficiency of PSII (Fv/Fm) of mini watermelon plants. The water mixtures caused significant effects on Fo ($p \leq 0.05$), Fm ($p \leq 0.01$), Fv ($p \leq 0.01$) and Fv/Fm ($p \leq 0.05$) of mini watermelon plants. Fo was also significant for substrates ($p \leq 0.01$) (Table 4).

There was no difference between the water mixtures for Fo and Fv/Fm by the Tukey test ($p \leq 0.05$) (Table 4). However, with the use of reject brine in the nutrient solution, there were reductions in Fm and Fv, mainly with the mixtures M_4 (55% TW + 45 % RB) and M_5 (40% TW + 60 % RB), with reductions of up to 5.71 and 7.05% in Fm and Fv of plants that received M_5 in the nutrient solution compared to the control (M_1), respectively.

Maximum fluorescence is defined as the fluorescence intensity at which all PSII reaction centers are open, that is, photochemical quenching is equal to zero and all photochemical quenching processes are at a minimum (photochemical quenching coefficient equal to zero) (Kooten & Snel, 1990). Differently, variable fluorescence (Fv) originates from the PSII pigment population and is sensitive to the rate of electron transport through reaction centers and to changes in the structure of thylakoid membranes (Georgieva & Yordanov, 1993). Despite the reductions in Fm and Fv, no change was observed in the maximum quantum efficiency of PSII (Fv/Fm), which corroborates the absence of significant effect of salinity on net photosynthesis. Thus, it can be affirmed that the 'Sugar Baby' mini watermelon plants were able to maintain energy stability even irrigated with water of 6.90 dS m^{-1} (M_5 = 40% TW + 60% RB).

Regarding the type of substrate, the highest Fo levels were obtained in plants grown in coconut fiber substrate (Table 4). According to Mouget & Tremblin (2002), the initial fluorescence is the fluorescence when Quinone A (PSII primary electron receptor quinone) is fully oxidized and the PSII reaction center is open, a situation that precedes the activation of the chemical reactions. For Baker & Rosenqvst (2004), the increase in Fo reveals destruction in the PSII reaction center or decrease in the excitation energy transfer capacity of the PSII antenna. However, such damage was not sufficient to significantly reduce the maximum quantum efficiency of PSII.

There was no significant effect ($p > 0.05$) of the interaction between water mixtures and substrates on electron transport rate (ETR), effective quantum efficiency of PSII (Y), photochemical quenching coefficient (qL), quantum yield of regulated photochemical quenching (Y_{NPQ}) and quantum yield of non-regulated photochemical quenching (Y_{NO}). There was significant effect ($p \leq 0.05$) of the water mixtures used on ETR ($p \leq 0.01$), Y_{II} ($p \leq 0.001$), Y_{NPQ} ($p \leq 0.001$) and Y_{NO} ($p \leq 0.01$). For the substrates, there were significant effects only on Y_{NO} ($p \leq 0.001$) and qL ($p \leq 0.01$) (Table 5).

Electron transport rate (ETR), quantum yield of regulated photochemical quenching (Y_{NPQ}) and quantum yield of non-regulated photochemical quenching (Y_{NO}) were increased by 68.51, 21.43 and 11.11% in plants that received M_5 (40% TW + 60% RB) in the nutrient solution compared to the control treatment (M_1 = 100% TW), respectively (Table 5). Regarding the effective quantum efficiency of PSII (Y_{II}), decreased by 8.66% in plants that received M_5 in the nutrient solution compared to the control treatment (M_1) (Table 5).

The reduction in the effective quantum efficiency of PSII (Y) (Table 5) confirms that there is lower photosynthetic performance of plants subjected to saline nutrient solutions (Klughammer & Schreibe, 2008); however, the increase in ETR is indicative of greater activity of the photosystem to compensate for photosynthetic activity and degradation

Table 4. Probability of F test and means comparison test for initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), maximum quantum efficiency of PSII (Fv/Fm) of mini watermelon plants in the vegetative stage subjected to different water mixtures used in the preparation of nutrient solution and types of substrate in hydroponic system, at 25 days after sowing

Sources of variation	Probability of F test			
	Fo	Fm	Fv	Fv / Fm
Block	0.7149	0.6227	0.6010	0.6083
Water mixtures	0.0479	0.0011	0.0012	0.0189
Substrates	0.0080	0.0844	0.2905	0.1453
Water mixtures x Substrates	0.0582	0.8161	0.7121	0.0766
CV (%)	6.25	4.59	5.75	2.15
	Means			
Water mixtures (M)				
M_1 - 100% TW (control)	960.00 a	3859.12 a	2899.12 a	0.7509 a
M_2 - 85% TW + 15% RB	1002.94 a	3801.87 ab	2798.94 abc	0.7357 a
M_3 - 70% TW + 30% RB	947.12 a	3802.06 ab	2854.94 ab	0.7504 a
M_4 - 55% TW + 45% RB	952.19 a	3651.87 b	2699.69 bc	0.7382 a
M_5 - 40% TW + 60% RB	944.19 a	3638.75 b	2694.56 c	0.7394 a
Substrates (S)				
S_1 - Coconut fiber	993.60 a	3783.05 a	2789.45 a	0.7366 a
S_2 - 100% Sand (S)	928.30 b	3662.85 a	2734.55 a	0.7455 a
S_3 - 70% S + 30% RH	972.05 ab	3774.55 a	2802.50 a	0.7416 a
S_4 - 40% S + 60% RH	951.20 ab	3782.50 a	2831.30 a	0.7478 a

Salinities of the water mixtures, in dS m^{-1}: M_1 - 0.54; M_2 - 2.40; M_3 - 4.00; M_4 - 5.48; M_5 - 6.90; CV - Coefficient of variation; TW - Tap water; RB - Reject brine; RH - Rice husk; Followed means of the same letter in the column do not differ from each other at $p \leq 0.05$ by Tukey test

Table 5. Probability of F test and means comparison test for electron transport rate (ETR), effective quantum efficiency of PSII (Y_{II}), photochemical quenching coefficient (qL), quantum yield of regulated photochemical quenching (Y_{NPQ}) and quantum yield of non-regulated photochemical quenching (Y_{NO}) of mini watermelon plants in the vegetative stage subjected to different water mixtures used in the preparation of nutrient solution and types of substrate in hydroponic system, at 25 days after sowing

Sources of variation	Probability of F test				
	ETR	Y_{II}	qL	Y_{NPQ}	Y_{NO}
Block	0.9221	0.7828	0.9342	0.7544	0.8993
Water mixtures	0.0022	0.0001	0.4596	0.0001	0.0024
Substrates	0.5753	0.1791	0.0009	0.1479	0.0060
Water mixtures x substrates	0.9471	0.5445	0.1196	0.6396	0.2871
CV (%)	48.85	6.06	18.90	12.74	11.69
	Means				
Water mixtures (M)					
M_1 - 100% TW (control)	59.22 bc	0.693 a	0.0079 a	0.252 c	0.054 b
M_2 - 85% TW + 15% RB	68.42 abc	0.643 bc	0.0075 a	0.295 ab	0.062 a
M_3 - 70% TW + 30% RB	56.01 c	0.677 ab	0.0085 a	0.269 bc	0.054 b
M_4 - 55% TW + 45% RB	93.49 ab	0.635 c	0.0083 a	0.305 ab	0.059 ab
M_5 - 40% TW + 60% RB	99.79 a	0.633 c	0.0081 a	0.306 a	0.060 ab
LSD	36.58	0.039	0.0015	0.036	0.006
Substrates (S)					
S_1 - Coconut fiber	78.93 a	0.652 a	0.0092 a	0.293 a	0.055 b
S_2 - 100% Sand (S)	68.91 a	0.665 a	0.0073 b	0.274 a	0.060 ab
S_3 - 70% S + 30% RH	83.09 a	0.642 a	0.0074 ab	0.297 a	0.061 a
S_4 - 40% S + 60% RH	70.60 a	0.666 a	0.0083 a	0.278 a	0.055 ab
LSD	30.82	0.033	0.0012	0.030	0.005

Salinities of the water mixtures, in dS m^{-1}: M_1 - 0.54; M_2 - 2.40; M_3 - 4.00; M_4 - 5.48; M_5 - 6.90; CV - Coefficient of variation; TW - Tap water; RB - Reject brine; RH - Rice husk; Means followed by the same letter in the column do not differ from each other at $p \leq 0.05$ by Tukey test of chlorophyll molecules (Tatagiba et al., 2014). On the other hand, the increase in quantum yield of non-regulated photochemical quenching (Y_{NO}) indicates that, in the absence of photochemical reactions, there is a reduction in chlorophyll formation and, consequently, in the production of free radicals and reactive oxygen species (ROS) (Laisk et al., 1997). There is also an increase in the quantum yield of regulated photochemical quenching (Y_{NPQ}), indicating that photoprotection is occurring in the active photosynthetic apparatus of these plants (Baraldi et al., 2008). This mechanism was efficient, since the CO_2 assimilation rate was not reduced.

Conclusions

1. Using the mixture of reject brine and tap water with electrical conductivity above 4.00 dS m^{-1} in the preparation of the nutrient solution applied in the study greatly reduces the growth of 'Sugar Baby' mini watermelon plants.

2. Using the mixture of reject brine and tap water with electrical conductivity of up to 6.90 dS m^{-1} in the preparation of the nutrient solution applied in the study does not reduce the net photosynthesis and quantum efficiency of photosystem II of mini watermelon plants.

3. Increments in carboxylation efficiency and activity in the electron transport chain act as tolerance mechanisms to compensate for the photosynthetic rate of mini watermelon plants under salt stress.

4. Coconut fiber promotes greater growth and photosynthetic activity for 'Sugar Baby' mini watermelon, while the substrate with 100% washed sand leads to the lowest performance.

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