DOI: 10.5433/1679-0359.2022v43n4p1497

Physiological and biochemical responses of mini watermelon irrigated with brackish water under two types of irrigation system

Respostas fisiológicas e bioquímicas de minimelancia irrigada com água salobra sob dois tipos de sistema de irrigação

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Highlights

Salinity up to 6.5 dS m^{-1} did not impair the photosynthetic apparatus.
Salinity increases non-regulated non-photochemical excitation dissipation.
Pulse drip irrigation does not attenuate the effects of salinity on mini watermelon.

Abstract

The use of marginal quality water can be a viable alternative in regions with water scarcity when associated with an adequate irrigation management strategy. The aim of this study was to evaluate the physiological and biochemical responses of 'Sugar Baby' mini watermelon as a function of irrigation management and salinity of the nutrient solution (ECsol). The experiment was carried out in a greenhouse of the Federal University of Recôncavo of Bahia, in the municipality of Cruz das Almas - BA, in a completely randomized design, with four replications. The plants were grown under two types of irrigation management (conventional drip - CD and pulse - PD) and four saline levels of the fertigation nutrient solution (2.5 - control; 4.5; 5.5; 6.5 dS m^{-1}).

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Received: June 06, 2021 - Approved: Apr. 25, 2022

At 65 days after cultivation, the following variables were evaluated: chlorophyll *a* and *b* content, chlorophyll *a* fluorescence, and organic and inorganic solutes content. The treatments did not influence the levels of chlorophyll *a* and *b*. Salinity decreased the quantum yield of photochemical energy conversion due to the increased quantum yield of unregulated energy loss. Irrigation management and water salinity did not affect carbohydrate content in mini watermelons leaves. However, soluble proteins were higher in the CD than in PD and decreased with increasing salinity in both managements. Salinity increased free amino acids in CD but did not change the content of these solutes in PD. Free proline was only influenced by the management system and was higher in CD than in PD. Sodium, chloride, and sodium to potassium ratio increased with ECsol, but these increases were more pronounced in PD. Salinity increased potassium content in PD and reduced in CD. The CD led to lower absorption of toxic ions, reducing the effects of salinity on the mini watermelon.

Key words: *Citrullus lanatus* L. Salt stress. Irrigation management.

Resumo

A utilização de água da qualidade marginal pode ser uma alternativa viável em regiões com escassez hídrica, quando associada a estratégias de manejo de irrigação adequadas. O objetivo deste estudo foi avaliar as respostas fisiológicas e bioquímicas da minimelancia ‘Sugar Baby’ em função dos manejos de irrigação e da salinidade da solução nutritiva (CEsol). O experimento foi realizado em casa de vegetação da Universidade Federal do Recôncavo da Bahia, no município de Cruz das Almas, BA, Brasil, em delineamento experimental inteiramente casualizados com quatro repetições. As plantas foram cultivadas sob dois tipos de manejo de irrigação (gotejamento convencional - GC e por pulsos – GP) e quatro níveis salinos da solução nutritiva de fertirrigação (2,5 - controle; 4,5; 5,5; 6,5 dS m^{-1}). Aos 65 dias após semeadura, foram avaliadas as variáveis: teores de clorofilas *a* e *b*, fluorescência da clorofila *a* e teores de solutos orgânicos e inorgânicos. Os tratamentos não influenciaram os teores de clorofila *a* e *b*. A salinidade diminuiu o rendimento quântico da conversão de energia fotoquímica com aumento na dissipação de energia não regulada, sendo que ambos são vias competitivas de energia entre si. O tipo de manejo e a salinidade não afetaram os teores de carboidratos nas folhas de minimelancia. Entretanto, as proteínas solúveis foram maiores no GC que no GP e diminuíram com o incremento da salinidade em ambos os manejos. A salinidade aumentou os aminoácidos livres no GC, mas não alterou o conteúdo destes solutos no GP. Os teores de prolina livre só foram influenciados pelo tipo de manejo, sendo maiores no GC que no GP. Os íons sódio e cloreto e a razão sódio/potássio aumentaram com a CEsol, sendo esses aumentos mais pronunciados no GP. A salinidade aumentou os teores de potássio no GP e diminuiu no GC. O GC levou a uma menor absorção de íons tóxicos, atenuando os efeitos da salinidade sobre a minimelancia..

Palavras-chave: *Citrullus lanatus* L. Estresse salino. Manejo de irrigação.

Introduction

Watermelon (*Citrullus lanatus* L.) is an annual cycle plant species belonging to the Cucurbitaceae family, being a vegetable commercially cultivated worldwide. According to the yearbook 2018 - 2019, watermelon cultivation in Brazil has high profitability, with an export of 52,900 tons in 2019, generating US$ 21.1 million, with the expectation of more positive seasons, especially with mini watermelons, which have exceeded export records (Hortifruitbrasil, 2020).

As water is a scarce resource in the Northeast region of Brazil, the success of watermelon production depends on the availability of water with proper irrigation management (Guimarães et al., 2016; Silva et al., 2017). Thus, a promising alternative to meet the water demand of crops is the use of marginal-quality water from surface and groundwater sources (wells) with a high concentration of salts (Sá et al., 2019). However, when plants sensitive to soil salinity are subjected to salt stress, ions such as Na^+ and/or Cl^- accumulate in chloroplasts, which may show physiological and biochemical changes due to toxic, osmotic, and nutritional effects (Silveira et al., 2016; Bai et al., 2019; Shoukat et al., 2019).

An example of biochemical change caused by the high concentration of salts in the soil is the accumulation of organic or osmotic solutes in the vacuole of plant cells, as a form of acclimatization to salt stress (Slama et al., 2015; Cova et al., 2020; F. D. A. Silva et al., 2020; Lo'ay & El-ezz, 2021). Another acclimatization mechanism is the cellular compartmentalization of inorganic ions in the vacuole, due to the ionic stress caused by salinity, when the plant increases the concentrations of toxic ions (Na^+ and Cl^-) in the vacuole and alters the ionic balance, reducing mineral absorption (Arif et al., 2020). In some species, high salinity reduces photosynthetic levels, total chlorophyll content, activity of the photosystem (PSII), potential quantum yield of photosystem II, besides degrading the structure of chloroplasts (Xu et al., 2018; Wang et al., 2018; Betzen et al., 2019).

According to Ayers and Westcot (1999), watermelon is considered moderately tolerant to irrigation water salinity, withstanding electrical conductivity of irrigation water (ECw) of up to 2.0 dS m^{-1}. Under normal growing conditions, the mass of mini watermelon fruits can reach up to 4.2 kg (Dutra et al., 2021). However, in mini watermelon, Sousa et al. (2016) reported that the use of brackish water (ECw between 1.0 and 5.0 dS m^{-1}) causes reductions in fruit mass of approximately 8.71% per unit increment in ECw. Nonetheless, irrigation with water above 3.5 dS m^{-1} is not recommended for the production of 'Sugar Baby' mini watermelon seedlings (Ó et al., 2020b).

In addition to the direct effects caused on plants, salinity also alters the chemical and physical properties of the soil, such as pH, water infiltration rate, and nutrient availability to plants (Blanco & Folegatti, 2002). Unlike most articles published with the use of brackish water, this study aims not only to evaluate the effect caused by salinity on the production of mini watermelon but also to minimize the negative effect induced by salinity with the use of water management techniques. Thus, searching for alternatives capable of mitigating the effects of salt stress on plants is of fundamental importance for plant growth and development, ensuring a high yield. Among the alternatives consistent with the conditions presented, pulse drip irrigation has shown promising effects (Zamora et al., 2019; Arriero et al., 2020).

As soil salinity affects water dynamics and reduces its availability to plants, the hypothesis of this study is that the use of pulse drip irrigation reduces the negative effects of salinity on the growth and metabolism of mini watermelon plants. Pulse drip irrigation is composed of a series of cycles that may vary depending on atmospheric demand, resting time, irrigation time, and other factors that can be adjusted according to the operator (Rank & Vishnu, 2021). Pulse drip irrigation has been studied, mainly due to the possibility of increasing water use efficiency in agricultural crops. Some studies with different crops showed positive results when using pulse drip irrigation, such as increased water use efficiency in lettuce (Almeida et al., 2015) and bell pepper (Barbosa et al., 2020), which also increased yield; increased shoot biomass index and decreased root mass in coriander (Zamora et al., 2019); and higher number of marketable fruits in eggplant (Arriero et al., 2020). In addition, the use of pulse drip irrigation has contributed to increasing the level and uniformity of soil moisture distribution (El-Abedin, 2006).

Increased water availability in the root zone can directly contribute to better absorption of water and nutrients and to the establishment of cell turgor, osmotic and ionic balance, and maintenance of leaf temperature, improving plant growth, especially under salt stress conditions (Taiz et al., 2017). However, these studies address only yield and water use efficiency with respect to pulse drip irrigation, with a noticeable scarcity of studies and experimental trials evaluating biochemical and physiological responses in watermelon using this technique with brackish water. In this context, the objective of this study was to evaluate the biochemical and physiological responses of ‘Sugar Baby’ mini watermelon plants grown under the management of continuous and pulse drip irrigation with brackish water.

Material and Methods

The study was carried out in a greenhouse in the experimental area of the Graduate Program in Agricultural Engineering of the Federal University of Recôncavo da Bahia, in Cruz das Almas (12°40'19" S, 39°06'23" W, 220 m), BA, Brazil. The climate of the study site is classified as Af (hot and humid tropical) according to Köppen’s classification (Alvares et al., 2013), with annual means of precipitation, air temperature, and relative humidity of 1,224 mm, 24.5 °C and 80%, respectively. During the experiment, the minimum and maximum values of air temperature inside the greenhouse were 19.8 and 36.5 ºC and the average relative humidity was 51%, respectively.

‘Sugar Baby’ mini watermelons were produced under fertigated conditions in a greenhouse (East-West orientation) from October to December 2018 (autumn-winter). The greenhouse used had a single-arch structure, with a ceiling height of 2.8 m, width of 7.0 m, and length of 24 m, protected on the sides by a screen and covered with 150-micron polyethylene film.

The experiment was carried out using a completely randomized design in a factorial scheme (4 × 2), with five replicates. The mini watermelon plants were subjected to four levels of electrical conductivity of the nutrient solution used in fertigation (ECsol): T1 - 2.50 (control, without NaCl), T2 - 4.50, T3 - 5.50, and T4 - 6.5 dS m^{-1}, and two types of irrigation management: conventional drip (CD) and pulse drip (PD).

The nutrient solution used in fertigation (NS) was based on the formulation of Sasaki (1992) for fruits. The following fertilizers were used (g $100L^{-1}$): 83 g of calcium nitrate, 50 g of potassium nitrate, 15 g of monoammonium phosphate (MAP), 36 g of magnesium sulfate, 6.7 g of potassium chloride, 0.01 g of copper sulfate, 0.09 g of zinc sulfate, 0.01 g of manganese sulfate, 0.12 g of boric acid, 0.015 g of sodium molybdate, and 1.6 g of Ferrilene (6% Fe + 40.8% EDDHA).

The NS was prepared using municipal-supply water, with ECw of 0.5 dS m^{-1}. The water ECw levels evaluated were: 0.5 (control), 1.0, 2.0, 3.0, and 4.0 dS m^{-1}. For the other treatments (ECsol above 2.50 dS m^{-1}), iodine-free NaCl was added to the nutrient solution to achieve the desired ECsol levels, using the relation between ECw and salt concentration, according to Eq. 1 (Richards, 1954):

$$Q\ NaCl\ (mg\ L^{-1}) = 640 \times ECw\ (dS\ m^{-1}) \qquad (1)$$

Where Q is the amount of salt to be dissolved in the water and ECw is the desired electrical conductivity of water.

Sowing was carried out in 200-mL plastic cups (perforated at the bottom and on the sides) containing only coconut fiber and irrigated initially with local-supply water (ECw=0.5 dS m^{-1}) and, after seven days, with nutrient solution of Sasaki (1992) at half strength (50% concentration). At 15 days after sowing (DAS), the seedlings with two true leaves were transplanted into 10-L containers filled with a mixture of coconut fiber and bovine manure (3:1 v/v), whose chemical analysis showed the following results: pH (water) = 6.7, P = 204 mg dm^{-3}, K = 5.2 $cmol_c$ dm^{-3}, Ca = 4.1 $cmol_c$ dm^{-3}, Mg = 4.7 $cmol_c$ dm^{-3}, Na = 1.78 $cmol_c$ dm^{-3}, Al = 0 $cmol_c$ dm^{-3}, H+Al = 3.57 $cmol_c$ dm^{-3} and OM= 71.5 g kg^{-1}.

The plants were grown with two stems and one fruit in the main branch, as described by Ó et al. (2020a). The experiment lasted 70 days. Harvest was carried out when the tendril adjacent to the fruit was dry (65 to 70 DAS).

The required irrigation depth was calculated based on the climatic data acquired from a weather station located in the center of the study area (greenhouse), composed of a pyranometer and thermo-hygrometer.

Evapotranspiration of watermelon crop (ETc) was calculated according to the methodology proposed by Allen et al. (1998) (Eq. 2):

$$ETc = Kc \times ETo \qquad (2)$$

Where ETc = crop evapotranspiration (mm day^{-1}); Kc = watermelon crop coefficient (dimensionless) and ETo = reference evapotranspiration (mm day^{-1}).

To calculate the daily ETo, an electronic spreadsheet was used, using the method adapted for studies in greenhouses recommended by Penman-Monteith, standardized by FAO 56 (Allen et al., 1998) with the wind speed set at 0.5 m s^{-1} (Eq. 3).

$$ETo = \frac{0.408\ \Delta\ (R_n - G) + \gamma \left(\frac{900}{T_a + 273}\right) u_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34\ u_2)} \qquad (3)$$

Where ET_o – reference evapotranspiration (mm day^{-1}); R_n – radiation balance (MJ m^{-2} day^{-1}); G – soil heat flux (MJ m^{-2} day^{-1}), G = 0 in a period of 24 h; Δ – declination of the water vapor saturation curve (kPa °C^{-1}); u_2 – wind speed at 2 m height (m s^{-1}), being for greenhouse conditions fixed at 0,5 m s^{-1}; T_a – average air temperature (°C); e_s – saturation pressure of water vapor in the atmosphere (kPa); e_a – current pressure of water vapor in the atmosphere (kPa) and γ – psychometric constant (MJ kg^{-1}).

The crop coefficients recommended by Silva et al. (2015) were used in the study: an initial Kc of 0.51 for nine days, vegetative Kc of 0.52 for 15 days, Kc flowering of 1.23 for 26 days and Kc of maturation of 1.13 for 10 days.

Thus, with the knowledge of all the data, the required irrigation depth was calculated by Eq. 4:

$$\mathrm{RID} = \frac{\mathrm{ETc}\ \mathrm{K_P}}{\mathrm{Ea}} \qquad (4)$$

Where RID – required irrigation depth (mm) and Kp - dimensionless location coefficient (considered 1); Ea – efficiency of water application of the system, adopting the value obtained by the uniformity test (0.95).

To calculate the operating time (Ti), the values of the irrigation depth required from Eq.5.

$$\mathrm{Ti} = \frac{\mathrm{LIN\ A}}{\mathrm{e\ q}} \qquad (5)$$

Where Ti - irrigation time for each treatment (h); A - area of containers, (m^2); e - number of emitters per plant (1) and q - average flow rate of the dripper (4.0 L h^{-1}).

Conventional drip (CD) and pulse drip (PD) irrigation management were performed daily. In the conventional drip irrigation management, water application was carried out uninterruptedly from 10 a.m., and in the pulse drip irrigation management, water application was split throughout the day as a function of atmospheric demand according to Ó et al. (2020a).

At 65 days after sowing (DAS), the variables of chlorophyll *a* fluorescence, chlorophyll (*a* and *b*) concentration indices, contents of organic solutes (soluble carbohydrates (CH), free proline (FP), free amino acids (AA), and soluble proteins (SP)) and inorganic solutes (sodium, potassium, and chloride) in the leaf adjacent to the mini watermelon fruit, located between the 8th and 10th node from the base. Before the analysis, the leaves were washed with distilled water and dried with paper towels.

Chlorophyll *a* and *b* concentration indices were determined using the electronic chlorophyll meter ClorofiLOG CFL1030 (Falker Automação Agrícola Ltda., Porto Alegre, RS) and the values were expressed in FCI (Falker Chlorophyll Index).

Chlorophyll *a* fluorescence variables were measured using the OS5p pulse-modulated portable fluorometer (Opti-Sciences, Hudson, USA). Leaves pre-adapted to a flow density of 1,000 μmol m^{-2} s^{-1} for 30 minutes in the dark were evaluated for minimum fluorescence (F_0), maximum fluorescence (F_m), and potential quantum yield of photosystem II - PSII (F_v/F_m) according to pulse saturation method (Schreiber et al., 1995). Leaves adapted to the light were evaluated for the yields of the competitive pathways of de-excitation of the energy absorbed in PSII were evaluated: the effective quantum yield of the photochemical energy conversion of PSII (Y_{II}) and quantum yields of regulated (Y_{NPQ}) and non-regulated (Y_{NO}) dissipation of non-photochemical energy in PSII, according to Kramer et al. (2004) and Klughammer and Schreiber (2008).

After the analyses of chlorophyll *a* fluorescence and chlorophyll concentration indices (*a* and *b*), the leaves were collected and divided into two, removing the central rib. Half of the leaf was packed with aluminum foil and immediately frozen and freeze-dried, while the other half was placed in a paper bag and dried in the oven at 65 ºC.

For the preparation of crude extracts of organic solutes, 0.1 g of freeze-dried leaf tissues were weighed and then macerated. After maceration, the samples were homogenized in phosphate buffer solution, distributed in Eppendorf tubes, and centrifuged with rotation of 12000 × g, for 00h:15 at 4 ºC. The supernatants were stored in a freezer for further analysis. Contents of soluble carbohydrates (Dubois et al., 1956), soluble proteins (Bradford, 1976), free proline (Bates et al., 1973), and free amino acids (Yemm & Cocking, 1955) were quantified.

For determining sodium (Na^+), potassium (K^+), and chloride (Cl^-) contents in leaves, the crude aqueous extracts were prepared as described by Jones (2001), with minor modifications. Na^+ and K^+ contents were determined by flame photometry according to Faithfull (2002) and Cl^- contents were determined according to Gaines et al. (1984). Na^+ and K^+ data were then used to calculate the sodium/potassium ratio (Na^+/K^+) in leaves.

The Shapiro-Wilk test was applied to the obtained data to check the distribution normality of the sample. Then, the data were subjected to analysis of variance by the F test. In the case of significant effect, the salinity levels, of quantitative nature, were subjected to linear and quadratic regression analysis. The types of irrigation management, of qualitative nature, when significant, were compared by the Tukey test at a 0.05 probability level. Statistical analysis was performed using SISVAR statistical software, version 5.6 (Ferreira, 2019).

Results and Discussion

According to the F test results (Table 1), there was a significant simple effect ($p<0.05$) of ECsol for Y_{II} and Y_{NO} and, the type of management on Y_{NO} and FP in leaves. There was a significant effect of the interaction between the factors (salinity × irrigation management) on the variables: SP and AA content in leaves, contents of Na^+, K^+ and Cl^- and Na^+/K^+ ratio in leaves.

Table 1

Summary of Fisher's test (F) and observed means for chlorophyll a fluorescence and biochemical variables in mini watermelon leaves

Source of variation	F Test							
	Chl a	Chl b	F_0	F_m	F_v/F_m	Y_{II}	Y_{NPQ}	Y_{NO}
Management (M)	ns	ns	ns	ns	ns	ns	ns	**
Salinity (S)	ns	ns	ns	ns	ns	**	ns	**
M x S	ns	ns	ns	ns	ns	ns	ns	ns
Mean	40.82	20.63	238.75	1254.57	0.8	0.27	0.55	0.18
CV (%)	4.36	10.56	8.35	4.17	1.8	13.94	7.36	8.93
SV	**CH**	**FP**	**SP**	**AA**	**Na^+**	**Cl^-**	**K^+**	**Na^+/K^+**
Management (M)	ns	*	ns	ns	**	**	**	**
Salinity (S)	ns	ns	**	**	**	**	ns	**
M x S	ns	ns	**	*	**	**	*	**
Mean	626.22	0.46	41.03	134.85	33.75	66.50	109.26	0.32
CV (%)	10.76	16.92	14.33	9.88	23.19	9.90	19.97	16.38

*, ** - significant at 0.05 and 0.01 probability levels, respectively; ns - not significant; CV - coefficient of variation; SV-source of variation; Chl *a* - chlorophyll *a* content; Chl *b* - chlorophyll *b* content; F_0 - minimal fluorescence; F_m - maximum fluorescence; F_v/F_m - potential quantum yield of photosystem II in oxidized state; Y_{II} - effective quantum yield of PSII photochemical energy conversion; Y_{NPQ} - regulated dissipation quantum yields; Y_{NO} - quantum yields of unregulated dissipation of non-photochemical energy in FSII; CH - soluble carbohydrates (μmol g^{-1} DM); FP - free proline (μmol g^{-1} DM); AA - free amino acids (μmol g^{-1} DM); SP - soluble protein (mg g^{-1} DM); Na^+ - sodium content in the leaf (mmol g^{-1} DM); K^+ - leaf potassium content (mmol g^{-1} DM); Na^+/K^+ - sodium and potassium ratio and Cl^- - leaf chloride content (mmol g^{-1} DM).

Effect of salt stress and irrigation management on chlorophyll a and b concentration indices and chlorophyll a fluorescence parameters in leaves of mini watermelon plants

No significant differences were found in chlorophyll a and b concentration indices, values of F_0, F_m, F_v/F_m and Y_{NPQ} between the treatments. The mean values observed were 40.82 FCI (Chl *a*), 20.62 FCI (Chl *b*), 238.75 (F_0), 1254.57 (F_m), 0.809 (F_v/F_m), and 0.553 (Y_{NPQ}) (Table 1).

When plants were exposed to high salinity, alterations or abnormalities occurred in the functional state of the thylakoid membranes of the chloroplasts, causing changes in the characteristics of fluorescence signals, which can be quantified in the leaves (Wang et al., 2018; Xu et al., 2018).

The increase in the number of chloroplasts caused by salinity can also affect photosynthetic pigments (Cova et al., 2020). However, in mini watermelon the salt stress may not induce synthesis or degradation, not being able to impair the transfer of energy from the antenna to the PSII reaction center and cause damage to the photosynthetic apparatus (Ribeiro et al., 2020; Ó et al., 2021).

According to Figure 1A, it was estimated that the highest yield (0.2980) of Y_{II} in mini watermelon plants was observed at the salinity of 3.8 dS m^{-1}, with a reduction from this point on. These Y_{II} values are within the range observed in mini watermelon cv. 'Sugar Baby' cultivated in a floating hydroponic system, in which Y_{II} varied from 0.3065 to 0.2421 between ECsol levels of 2.5 and 6.5 dS m^{-1}, respectively (Ó et al., 2021). Regarding Y_{NO}, plants irrigated with water of 6.5 dS m^{-1} had an increase of 13.88% compared to plants irrigated with water of 2.5 dS m^{-1} (Figure 1B).

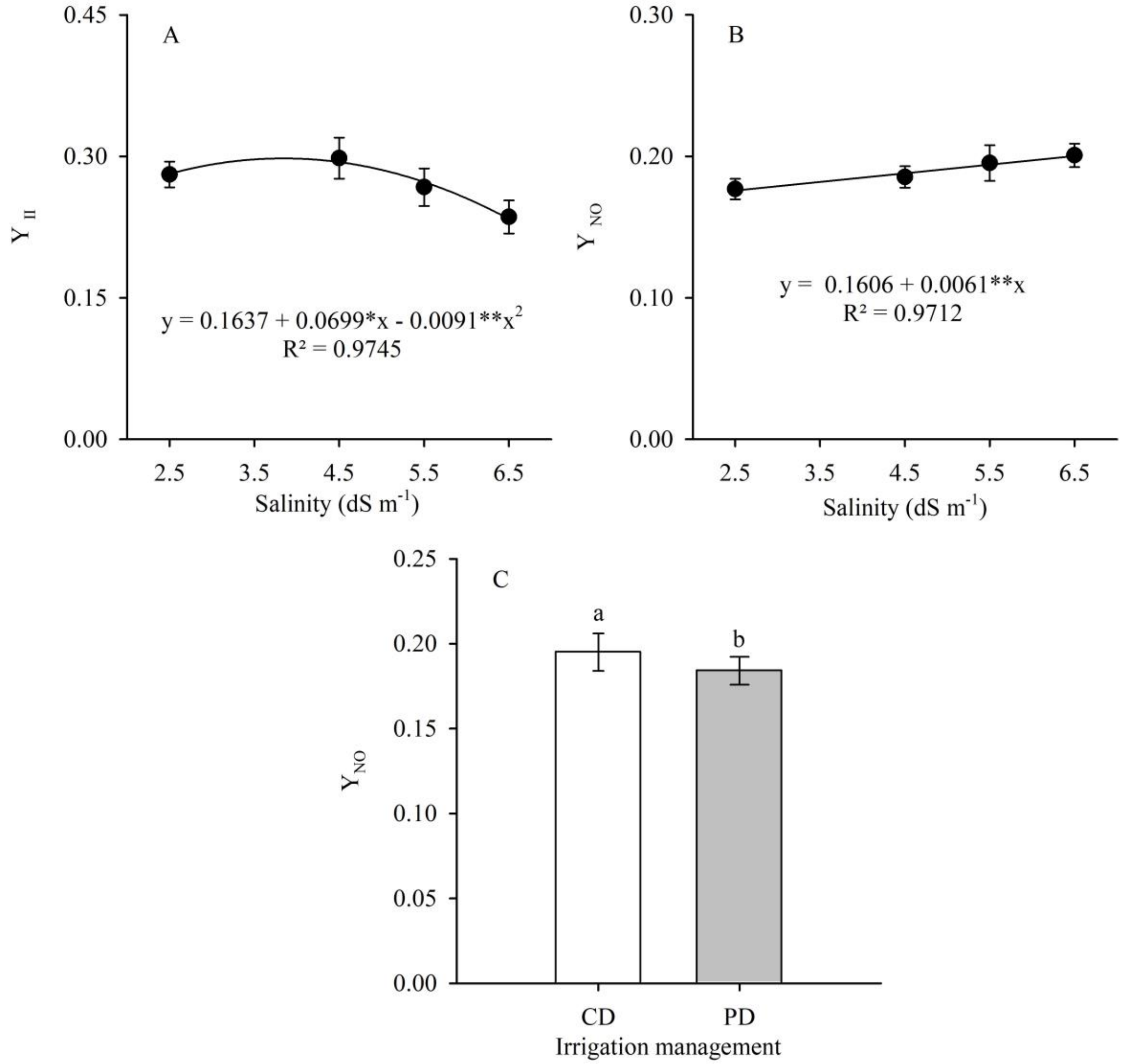

Figure 1. Quantum yield of photochemical energy conversion of PSII - Y_{II} (A) and quantum yield of unregulated energy loss - Y_{NO} (B and C) in leaves of 'Sugar Baby' mini watermelon plants after 65 days of cultivation in a greenhouse, as a function of the electrical conductivities of the nutrient solution (ECsol) and the irrigation management used (CD - conventional drip; PD- pulse drip). Vertical bars represent standard errors (n = 4). Means followed by the same letters do not differ by Tukey's test at 0.05 significance. *, ** - significant, respectively, at 0.05 and 0.01 probability, by the F test.

As observed, the reduction in Y_{II} values at the highest salinity levels was accompanied by increased Y_{NO}, since these are energy dissipation mechanisms that compete with each other (Eskling et al., 1997). This decrease in Y_{II} results in an energy surplus in the reaction center, increasing the dissipation of energy inside the antenna, in the form of heat or fluorescence emission (Oliveira et al., 2018).

In general, plants respond to stress conditions by activating mechanisms of acclimatization to the new environment (Dias et al., 2021). When stress is strong or prolonged enough, an inhibition occurs in the electron transport chain, observed by the decrease in Y_{II}. This inhibition of light-dependent reactions may be accompanied by an increase in Y_{NO} (Pérez-Bueno et al., 2019). Additionally, Mathobo et al. (2017) state that the increase in Y_{NO} may have been caused by the large proportion of light energy that is not being used by plants in the photosynthetic process.

The type of management also significantly influenced the Y_{NO} variable, therefore, the value under PD was 5.59% higher than under CD (Figure 1C). Ó et al. (2020a) emphasize that water application by pulse drip irrigation (PD) can result in a greater accumulation of salts on the substrate surface. In contrast, the uninterrupted application of water in CD can increase the transport of salts to the lower layers of the substrate. Thus, PD may have increased salt stress and, consequently, the need to dissipate excess energy.

Effect of salt stress and irrigation management on the contents of organic solutes in leaves of mini watermelon plants

CH contents were not influenced by water salinity (ECsol) or irrigation management, showing an average value of 626.22 μmol g^{-1} DM (Table 1). Understanding the response of plants to some stress is extremely complex since the efficiency of physiological and biochemical mechanisms depends on the species, genotype, and concentration and composition of salts in irrigation water or soil solution (Rodrigues et al., 2019). Under high salinity, some plants tend to accumulate soluble carbohydrates as a defense mechanism against stress (Slama et al., 2015; D'Amelia et al., 2018), but this response may not happen in some species, as observed in this study (Mastrogiannidou et al., 2016).

When analyzing the FP contents in the leaves, it was noted that in the CD they were 19.57% higher than the values found in plants under PD plants (Figure 2A). Thus, considering that the proline contents decrease with salinity and the observation that the FP under PD was lower than under CD, the hypothesis that water application by CD may have attenuated the effects of salinity on mini watermelon plants is supported. Therefore, it is believed that in mini watermelon, the reduction of FP can be a response to salinity and not the accumulation of this solute. As observed in this study, Ó et al. (2021) reported a reduction in FP content in hydroponic mini watermelon plants under high salinity (6.5 dS m^{-1}), suggesting that FP may not have played a key role in the osmoregulation mechanism.

Regarding the SP content, an analysis of the interaction between the factors (Figure 2B) showed that, among the types of irrigation management, the contents were higher in PD. Regarding salinity, there were reductions of 10.07% under CD and 9.40% under PD per unit increment in ECsol. It is believed that under high salinity some plants may reduce the content of soluble proteins (Gondim et al., 2011; Ó et al., 2021). Thus, the reductions observed in the SP contents in both systems (PD and CD) demonstrate that this type of management may have increased stress, reducing protein synthesis, or increasing the production of secondary metabolites (Batista-Silva et al., 2019). Therefore, it is clear that these biochemical responses in mini watermelon showed a behavior similar to that observed in FP.

AA contents were not influenced by salinity under PD, but the data were described by the linear model under CD, with an increase of 10.96% per unit increment in ECsol. Thus, it can be observed that in the treatment of the highest salinity (6.5 dS m^{-1}) the AA content under CD was 14% higher than under PD (Figure 2C). This accumulation of amino acids in the leaves due to the increase in nutrient solution salinity may be the result of increased activity of proteolytic enzymes, increasing the availability of this solute to protect plant tissues, in this specific case, the leaf, against stress (Galdino et al., 2018). In addition, there may also be an increase in the rates of biosynthesis of amino acids under stress conditions (Batista-Silva et al., 2019).

Effect of salt stress and irrigation management on the contents of inorganic solutes in leaves of mini watermelon plants

The Cl^- contents in the leaves increased quadratically, and this increase was more pronounced under PD than under CD (Figure 3A). When comparing the treatment of highest salinity of the nutrient solution (6.5 dS m^{-1}) with the control (ECsol = 2.5 dS m^{-1}), increases of 121 and 205% were observed under CD and PD systems, respectively.

Salinity linearly increased Na^+ contents under both management systems and, as observed for Cl^-, the increase was more visible under PD (562%) than under CD (342%) when comparing the values estimated in the treatment of 6.5 dS m^{-1} with that of 2.5 dS m^{-1} (Figure 3B). Contrary to what was observed for Na^+ and Cl^-, the K^+ content under CD decreased by 6.41% per unit increase in salinity and increased by 6.41% under PD (Figure 3C).

Figure 3 also shows that the contents of inorganic solutes (Cl^-, Na^+, and K^+) under PD were higher than under CD, except in the treatment of 2.5 dS m^{-1}, in which there was no significant difference between irrigation management. Thus, in the treatment of highest salinity (6.5 dS m^{-1}), the contents of Cl^-, Na^+, and K^+ under PD were, respectively, 22.47, 77.66, and 117.94% higher than those observed under CD.

The Na^+/K^+ ratio increased linearly with the increase in nutrient solution salinity under both management systems. Mathematical simulation in treatments 2.5 and 6.5 dS m^{-1} predicts an increase in the Na^+/K^+ ratio from 0.094 to 0.556 (494%) under CD and from 0.096 to 0.438 (358%) under PD (Figure 3D).

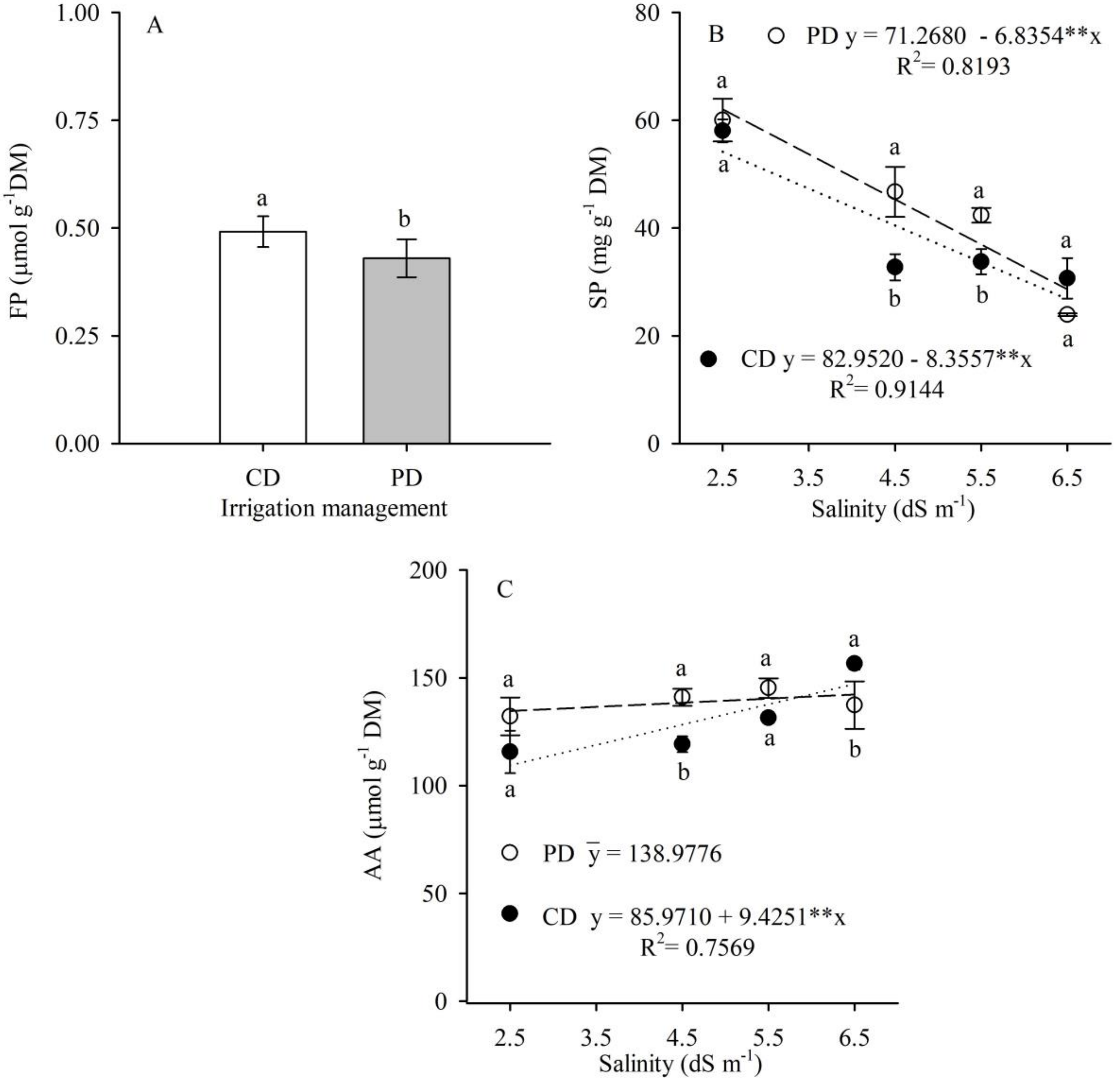

Figure 2. Contents of free proline - FP (A), soluble protein - SP (B), and free amino acids - AA (C) in leaves of 'Sugar Baby' mini watermelon plants after 65 days of cultivation in a greenhouse, as a function of electrical conductivities of the nutrient solution (ECsol) and the irrigation management used (CD - Conventional drip; PD - Pulse drip). Vertical bars represent standard errors (n = 4). Means followed by the same letters do not differ by Tukey's test at 0.05 significance. *, ** = significant, respectively, at 0.05 and 0.01 probability, by the F test.

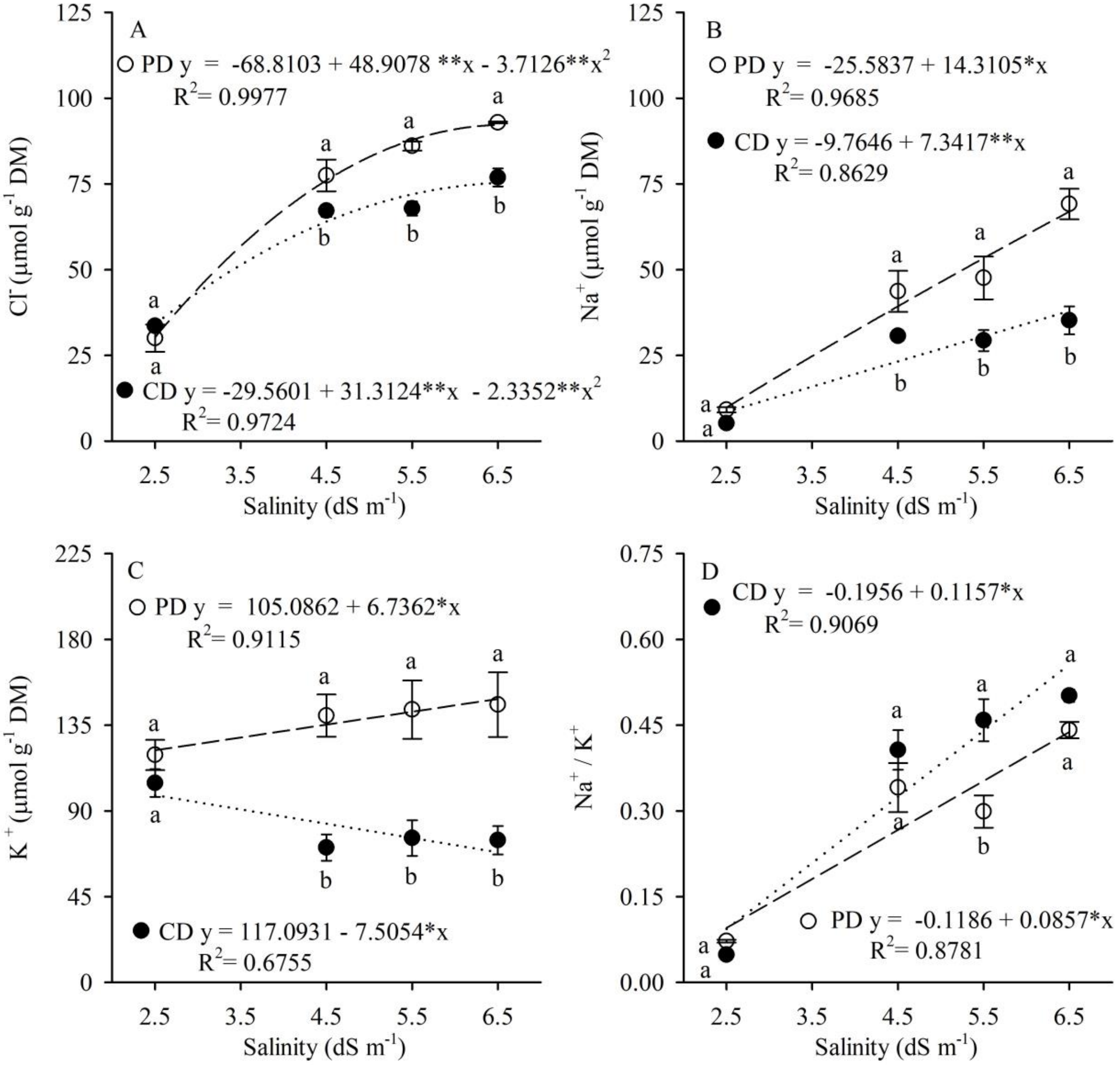

Figure 3. Chloride - Cl^- (A), sodium – Na^+ (B), potassium- K^+ (C), and Na^+/K^+ ratio (D) contents in leaves of 'Sugar Baby' mini watermelon plants after 65 days of cultivation in a greenhouse, as a function of the electrical conductivities of the nutrient solution (ECsol) and the irrigation management used (CD - continuous drip; PD - pulse drip). Vertical bars represent standard errors (n = 4). Means followed by the same letters do not differ from each other by the Tukey test, at 0.05 of significance. *, ** = significant, respectively, at 0.05 and 0.01 probability, by the F test.

The accumulation of Na^+ and Cl^- ions in plants subjected to salinity is widely reported in the literature (Menezes et al., 2017; Bai et al., 2019; Arif et al., 2020). Plants commonly accumulate these ions in the vacuole, which contributes to the osmotic adjustment mechanism (Taiz et al., 2017). This accumulation of Na^+ and Cl^- ions as a mechanism of salinity tolerance has also been reported in watermelon crop by E. G. Silva et al. (2017) and Ó et al. (2021).

The Na^+/K^+ ratio is an important variable in the assessment of the risk of ionic toxicity due to exposure to salt stress, and values equal to or lower than 1.0 are considered adequate for optimal metabolic efficiency in non-halophytes (Greenway & Munns, 1980). In this work, the maximum estimated values for the Na^+/K^+ ratio under both irrigation management systems suggest that, even under a high salinity of irrigation water (ECsol = 6.5 dS m^{-1}), cell metabolism was not affected by salt-induced ionic imbalance. Similar results were reported by Ó et al. (2021) in 'Sugar Baby' mini watermelon cultivated in a floating hydroponic system.

When comparing the effect of the types of irrigation management on inorganic solutes (Cl^-, Na^+, and K^+), it is interesting to note that the highest concentrations were observed under PD. As previously hypothesized, this type of management may have contributed to a higher concentration of salts in the surface layer of the substrate, when compared to CD (Ó et al., 2020a). Although PD optimizes the consumption of water and nutrients, in irrigation with brackish water it can increase the absorption of salts and consequently cause greater salt stress, as the rhizosphere is kept wet for longer, favoring the rate of absorption of water and ions (El-Abedin, 2006; Zamora et al., 2021). The observation that the Cl^-, Na^+, and K^+ contents were significantly higher under PD supports this hypothesis.

Conclusions

An increase in salinity under both types of irrigation management, conventional drip or pulse drip, does not alter the concentration indices of chlorophylls *a* and *b* in leaves of mini watermelon plants, but reduces the ability to convert the energy of photons into chemical energy, verified through the results observed in Y_{II}.

In mini watermelon, the reduction in proline and soluble protein contents may be a response to salinity. Pulse drip management (PD) facilitates the absorption of ions, whether toxic or not, but conventional drip management (CD) attenuates the effects of salinity on inorganic solute contents.

Acknowledgments

Authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES), the National Council for Scientific and Technological Development (CNPq), Bahia State Research Support Foundation (FAPESB) and Federal University of Recôncavo of Bahia (UFRB), for the financial support over the years.

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