

# Biometrics, physiology, production, and quality of Cantaloupe melons grown with saline waters under semi-arid conditions

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## Abstract

Brazilian Northeast region emerges as both producer and exporter relevant of cantaloupe melon to several countries; however, this region is vulnerable to salinization problems due to it is inserted in a semi-arid area. This study aimed to evaluate the biometrics, physiological, production and quality of new cantaloupe melon hybrids cultivated with different saline waters under semi-arid conditions. The experiment was conducted using a drip irrigation system in a split-plot randomized design. The plot was different irrigation water electrical conductivity (ECw) levels: 0.5, 2.0, 3.5, and 5.0 dS m<sup>-1</sup>, while the subplot was two new cantaloupe melon hybrids: Zielo and SV1044. Plant biometrics (stems and leaves analysis), plant physiology (solute accumulation and gas exchange in leaves), fruit production (number, weight, and yield), and fruit quality (physical and chemical analysis) were investigated. Stem length, leaf numbers, leaf area, and shoot dry mass decreased when ECw increased from 0.5 to 5.0 dS m<sup>-1</sup>. Also, there was an increase of Na and Cl concentration and reduction of K concentration in leaves due to ECw increase. Gas exchange reduction, losses in fruit numbers, weight, yield, and in quality were observed with the ECw increase. It is possible to conclude that the ECw increase salinizes the soil and increases Na and Cl concentration in plants causing reduction in gas exchange, in growth, and in fruit production and quality. However, the response of cultivated hybrids regarding salinity may be different, as in our study that the Zielo hybrid was less affected by the increase in ECw.

**Keywords:** *Cucumis melo* L., gas exchange, soluble solids

## Introduction

Melon world production in 2018 was 27.35 million tons becoming one of the most important and widely cultivated crop (FAO, 2018). Brazilian melon production in 2018 was 581 thousand tons in 23 thousand hectares. Brazilian Northeast emerges as the main export region of national fruits and the largest producer of melon. The melon production in this region was 555 thousand tons in 2018, 95.5 % of total Brazilian melon production (IBGE, 2018).

The cantaloupe melon has salmon pulp with strong and pleasant aroma (Alves et al., 2000). This fruit is produced worldwide, including in Brazil semi-arid area. Brazil has recently increased cantaloupe melon cultivation area due to high demand in international market. The constant insertion of new melon hybrids has been observed to supply exportation demand, but these new hybrids are being grown without well-defined

agronomic knowledge in response to salinity problems presented in producing areas.

Melon production in Brazil semi-arid area has some edaphoclimatic conditions favorable and water sources availability (Gurgel et al., 2010). However, due to this semi-arid area has a high evaporation rate in relation to precipitation, irregular precipitation regimes, underground soils with almost 70 % of crystalline rocks and irrigation waters almost exclusively from artesian reservoirs with high salinity levels (Cosme et al., 2018), it difficult to produce cantaloupe melons with quality.

Salinity is one of abiotic stresses that limits severely crop growth and yield due to water potential reduction, ionic toxicity and nutrient imbalance (Munns & Tester, 2008). The low water potential can cause morphological adaptations as well as physiological responses. Morphological adaptations in plants include decline in growth rate, and modification of root to shoot ratio for

desiccation avoidance (Hund et al., 2009). Physiological responses include reduced photosynthetic rate, leaf water potential, and transpiration rate (Morais et al., 2018).

Therefore, this study aimed to evaluate the biometrics, physiological, fruit production and quality characteristics of new cantaloupe melon hybrids cultivated with different saline waters under semi-arid conditions.

## Material and Methods

The field experiment was conducted from November 2015 to January 2016 at Pacajus Experimental Station (Embrapa Agroindústria Tropical), located at 4°10' S, 38°27' W at an altitude of 60 m, Ceará State, Brazil. The soil was classified as Typic Quartzipsamment (Quartz Sand) according to Soil Taxonomy from Soil Survey Staff – USDA (2014) and its characteristics are reported in Table 1.

**Table 1.** Soil characteristics from 0 to 0.3 m depth.

pH	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Al <sup>3+</sup>	H+Al	SB	CEC	BS	P
H <sub>2</sub> O					cmol <sub>c</sub> kg <sup>-1</sup>				%	mg dm <sup>-3</sup>
6.3	0.40	0.40	0.07	0.13	0.10	1.20	1.00	2.20	45.00	7.20
EC	ESP	C	N	OM	C/N	BD	PD	FC	WP	H <sub>2</sub> O
dS m <sup>-1</sup>	%	g Kg <sup>-1</sup>		g cm <sup>-1</sup>		g 100g <sup>-1</sup>				
0.29	3.00	2.28	0.19	3.93	12.00	1.76	2.63	2.98	2.00	0.98

SB: Sum of bases; CEC: Cation exchange capacity; BS: Base saturation; EC: Electrical conductivity; ESP: Exchangeable sodium percentage; OM: Organic matter; BD: Bulk density; PD: Particle density; FC: Field capacity (0.033 MPa); WP: Permanent wilting point (1.5 MPa); H<sub>2</sub>O: Available water.

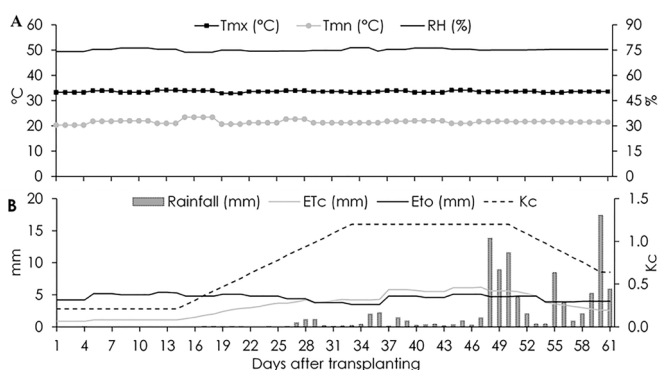
The climate of area was classified as BSh by Köppen methodology. This climate is tropical with rains in the summer season and dry winter. Maximum and minimum temperatures (°C), and relative humidity (%) were evaluated through an automated weather station (Figure 1A). Rainfall during the experimental period was 100 mm (Figure 1B).

irrigation system was installed with one irrigation line per bed. These beds were covered with double-face black/silver plastic mulch, with silver side up. Seedlings were spaced every 0.8 m in the line.

Plants were fertilized at the base and by fertigation according to the soil analysis obtained from Embrapa's Soil Laboratory (Table 1). The bed base fertilization consisted in application of 120 kg ha<sup>-1</sup> of phosphorus as single superphosphate, 250 kg ha<sup>-1</sup> of frites FTE BR-12 as micronutrients source and 20 m<sup>3</sup> ha<sup>-1</sup> of bovine fertilizer. Fertigation was applied three times a week, from a nutrient stock prepared in 20 L container and by a Venturi injector in bypass system. Nutrients used in the fertigation were 120 kg ha<sup>-1</sup> of nitrogen as urea and 120 kg ha<sup>-1</sup> of potassium as white potassium chloride. The fertigation was applied from transplanting to two weeks before fruit harvest, similar to the management adopted by melon producers in the semi-arid area.

Saline waters for irrigation of plants were prepared and stored in different water reservoirs of 5,000 L. They were translocated to plants by a pump of 0.5 CV and PVC lines with 20 mm diameter for main lines and 16 mm diameter for irrigation lines. Irrigation lines had water drippers with compensated pressure (2 bar) and flow rate 4.7 L h<sup>-1</sup>, spaced 0.8 m corresponding one per plant. The water distribution efficiency was indicated by the coefficient of uniformity with a value of 95.5 % from the flow rate data.

Melon plants water requirement was calculated from the "IrrigaMelão" spreadsheet, provided by EMBRAPA (2020). This spreadsheet considers the data collected in an automated weather station to determine the reference evapotranspiration (ET<sub>0</sub>) (Figure



**Figure 1.** Meteorological and water requirement data. (A): maximum (Tmx) and minimum (Tmn) temperature in °C, and relative humidity (RH) in %. (B): rainfall, reference evapotranspiration (ET<sub>c</sub>), and crop evapotranspiration (ET<sub>o</sub>) in mm, and crop coefficient (K<sub>c</sub>).

Cantaloupe melon seedlings of Zielo and SV1044 hybrids were obtained from the sowing in 200-cell polypropylene trays containing commercial substrate Forth Soil Conditioner. These seedlings were acclimated in a greenhouse with misting and then transplanted to the experimental area 10 days after sowing when plants had two true leaves.

The soil of experimental area had its base saturation increased by applying dolomitic limestone, raising from 45 % to 80 %. After liming, the soil received two light disking, and raising of cultivation beds with 0.8 m W x 21 m L and two-meter spacing between beds. Drip

1B) according to Penman-Monteith methodology. In addition to  $ET_0$ , the crop coefficient (Kc) (Figure 1B) was considered for the melon crop according to Miranda et al. (1999). Crop evapotranspiration (ETc) (Figure 1B) was determined by multiplying  $ET_0$  by the Kc. The irrigation time in hours was calculated automatically by "IrrigaMelão" spreadsheet (EMBRAPA, 2020).

Irrigation lines were arranged in a completely randomized design in a split-plot treatment design, with eight treatments and four replicates, totaling sixteen plots and thirty-two subplots. The plot, of quantitative order, consisted to different irrigation water electrical conductivity (ECw) levels: 0.5, 2.0, 3.5, and 5.0 dS m<sup>-1</sup> and each level had four irrigation lines representing four replicates (16 plots). To obtain ECw 2.0, 3.5, and 5.0 dS m<sup>-1</sup>, the 0.5 dS m<sup>-1</sup> water was used with addition of sodium chloride (NaCl), and the values confirmed and monitored by a conductivity meter CD-4301 model from Lutron (Taipei, TW). The subplot, of qualitative order, consisted of two new cantaloupe melon hybrids: Zielo and SV1044.

Plant biometrics and physiology were analyzed in three different growth stages: vegetative stage - VS (19 days after transplanting - DAT), fructification stage - FS (40 DAT) and harvesting stage - HS (61 DAT). Gas exchange and water-use efficiency were analyzed just in the vegetative and harvesting stage. Fruit production and quality variables were analyzed at the end of the crop cycle.

The soil salinity was analyzed from the soil electrical conductivity of saturation extract (ECe) measured by direct contact of conductivity meter WET-1 from Delta-T Devices (Cambridge, UK) with the saturated paste. Soil samples were collected in each plot using a soil collector TS-100 from Sondaterra (São Paulo, BR). These samples were collected 10 cm distance from plants and from 0 to 0.3 m depth. The ECe data was used to elaborate ECe-ECw equation.

The plant biometrics variables analyzed were stem length (SL), stem diameter (SD), leaf numbers (LN), leaf area (LA), and shoot dry mass (SDM). The leaf area was measured using a photoelectric integrator LI-3000 from LICOR (Nebraska, USA).

The plant physiology variables analyzed were gas exchange and solutes accumulation (organic and inorganic solutes) in leaves. Gas exchange were CO<sub>2</sub> assimilation rate (A), stomatal conductance (gs), and leaf transpiration (E). Water-use efficiency (WUE) was obtained from the A/E ratio. These analyzes were measured using an infrared gas analyzer - IRGA from LCpro ADC (Hoddesdon, UK) on mature leaves of the

primary stem, from 10:00 a.m. to 11:00 a.m.

Solutes accumulation in leaves analyzed were total sugar (TS), potassium (K), sodium (Na), and chloride (Cl) concentration in leaves. Leaves were dried and then, an extract of 1 g of dry leaf to 50 mL of water was prepared. From this extract, TS was determined by reactions with sulfuric acid and 5% phenol, both K and Na ions were determined by flame photometry, and Cl ion was determined by molecular absorption spectrophotometry.

Fruit variables were analyzed in production and quality. The fruit production variables analyzed were fruit numbers (FN), fruit weight (FW), and fruit yield (FY). The fruit physical quality variables analyzed were longitudinal (LD) and equatorial diameter (ED) of fruit, thickness (PuT) and firmness (PuF) of pulp, and peel thickness (PeT). The fruit chemical quality analyzed were soluble solids (SS), total sugars (TS), sucrose (Suc), glucose (Glu), and fructose (Fru). Sugars were quantified by high-performance liquid chromatography HPLC RID-10A from Shimadzu (Kyoto, JP), with refractive index detection, using a Ca<sup>2+</sup> column from Supelco, with isocratic liquid phase of water and flow of 0.5 mL min<sup>-1</sup>.

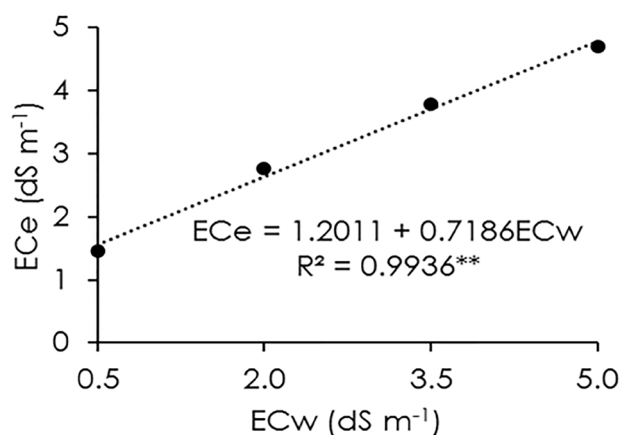
The data analysis of variance (ANAVA) was performed using *F* test and considering the split-plot treatment design, with irrigation water electrical conductivity (ECw) and cantaloupe melon hybrids (Hyb) as factors. When there was a significant effect on ANAVA, the ECw factor of quantitative order was submitted to linear regression analysis, and the Hyb factor of qualitative order was submitted to Tukey's test at the 5 % significance level. Statistical analysis were carried out using the SISVAR statistical software (Ferreira, 2000).

## Results

The equation between ECe and ECw, at the end of the crop cycle and from 0 to 0.30 m depth, was linear and increasing, indicating a positive relation between these conductivities (Figure 2).

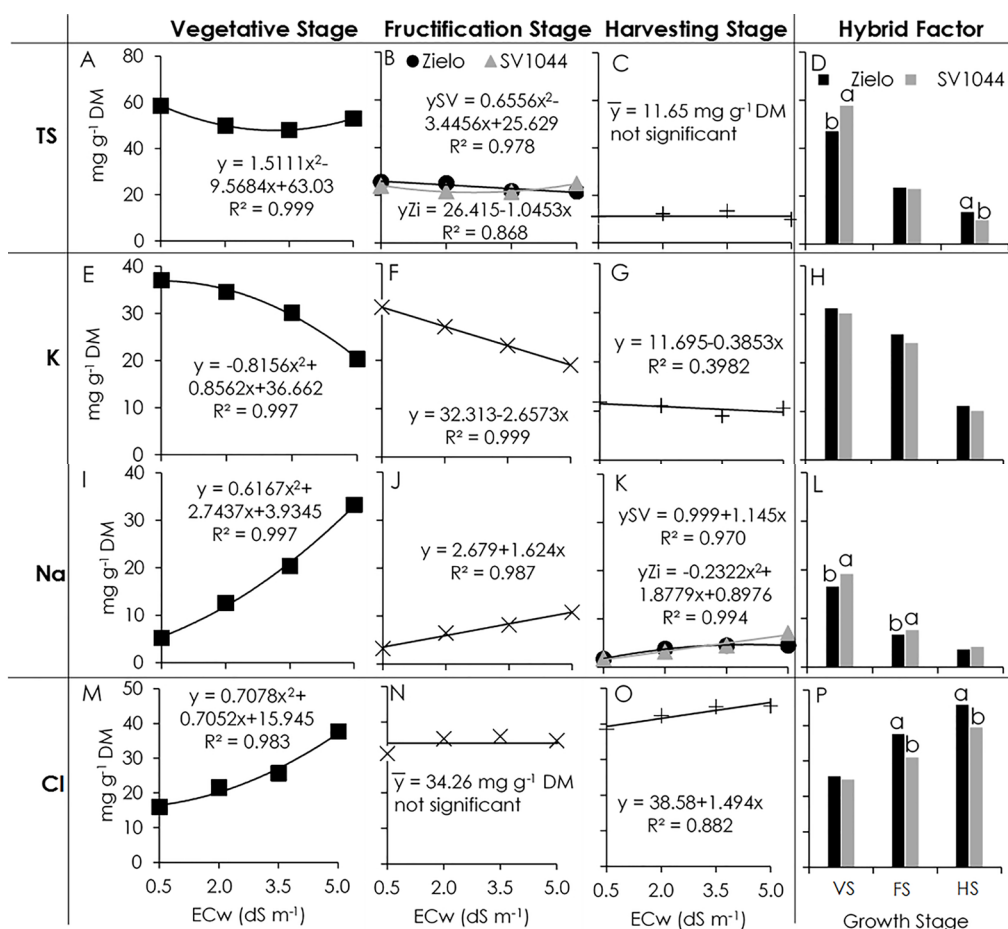
Evaluating solutes accumulation (organic and inorganic) in leaves, there was interaction between ECw and Hyb to total sugar (TS) in the fructification stage (Figure 3B) and to sodium (Na) concentration in the harvesting stage (Figure 3K). The ECw factor did not influence Cl concentration in the fructification stage (Figure 3N) and TS in the harvest stage (Figure 3C). Potassium (K) concentration had significant difference to salinity factor in isolation, while to hybrid factor there was no significant difference (Figure 3E, F, G, H).

Analyzing the vegetative stage in Figure 3, while TS and K concentration in leaves responded inversely



**Figure 2.** Equation between soil electrical conductivity of the saturation extract (ECe) and irrigation water electrical conductivity (ECw), at the end of the crop cycle. \*\* Significant at 1% of probability (P < 0.01).

proportional to the ECw increase (Figure 3A, E), Na and Cl concentration responded directly proportional to the ECw increase (Figure 3I, M). The TS concentration, regardless of hybrid, decreased until the ECw = 3.17 dS m<sup>-1</sup> and after increased (Figure 3A). In relation to K concentration, the decrease was 45 % (Figure 3E) between the lowest (0.5 dS m<sup>-1</sup>) and highest (5.0 dS m<sup>-1</sup>) ECw levels analyzed. Na and Cl concentration increased by 538 % and 135 %, respectively, between the lowest and the highest ECw levels (Figure 3I, M). SV1044 hybrid, regardless of ECw, presented a higher concentration of TS and Na in leaves when compared to Ziolo hybrid (Figure 3D, L).



**Figure 3.** Organic and inorganic solutes concentration in cantaloupe melon leaves. Each graphs row is represented by variables, and each graphs column is represented by growth stage and by hybrid factor in isolation. Total sugars - TS (A, B, C, D), potassium - K (E, F, G, H), sodium - Na (I, J, K, L) and chloride - Cl (M, N, O, P) concentration. Markers: (■) vegetative stage, (x) fructification stage, and (+) harvest stage to salinity factor in isolation. Values followed by different lowercase letters are significantly different at P < 0.05 in relation to hybrid factor in isolation.

In the fructification stage, TS concentration in SV1044 leaves remained higher than in Ziolo from the ECw = 3.96 dS m<sup>-1</sup> (Figure 3B). K and Na concentration presented similar response to the previous stage. K concentration decreased 39 % (Figure 3F) and Na concentration increased 222 % (Figure 3J). Cl concentration remained

constant between saline levels with mean 34.26 mg g<sup>-1</sup> of dry mass (DM) (Figure 3N). Sodium concentration remained higher in SV1044 hybrid leaves than in Ziolo hybrid (Figure 3L), regardless of ECw analyzed.

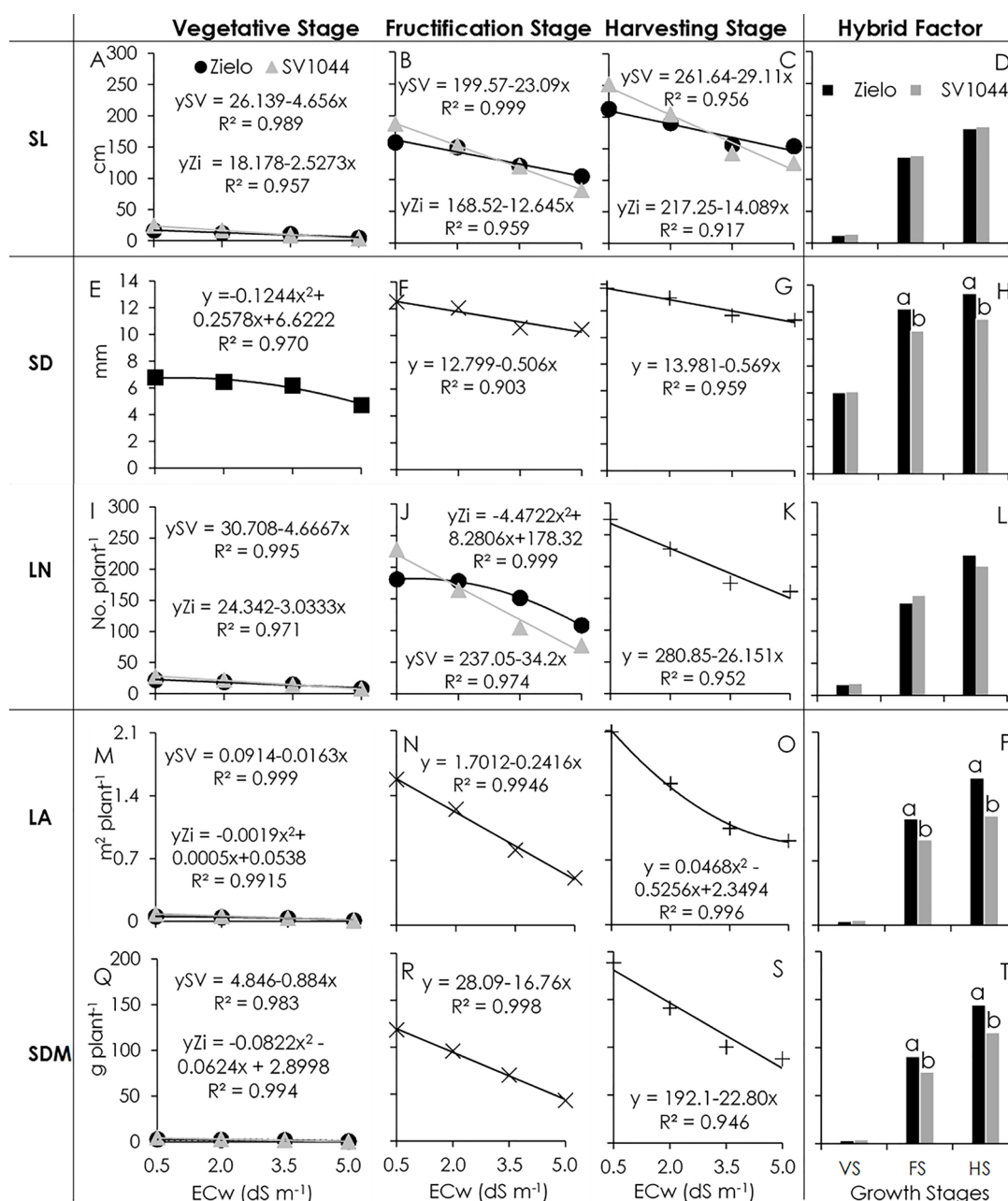
In the harvesting stage, there was no significant difference between ECw levels for TS concentration and

the mean was 11.65 mg g<sup>-1</sup> DM (Figure 3C), however the Zielo hybrid leaves presented higher TS concentration in relation to SV1044 (Figure 3D). K concentration decreased 10 % (Figure 3G) and Cl increased 17 % (Figure 3G) comparing ECw levels from 0.5 to 5.0 dS m<sup>-1</sup>. Sodium concentration increased similar among hybrids until ECw = 3.0 dS m<sup>-1</sup>, and after this ECw the SV1044 hybrid continued to increase while in Zielo stabilized (Figure 3K).

In relation to plant biometrics variables analyzed, there was a higher interaction between factors (ECw x Hyb) in the vegetative stage than in the other stages

(Figure 4A, I, M, Q). The stem diameter was the only variable that had no significant interaction throughout the melon growing cycle (Figure 4E, F, G).

Analyzing the vegetative stage in the Figure 4, excluding stem diameter (SD) (Figure 4E) in which hybrids were impacted negatively by ECw in the same proportion, for the others biometric variables ECw increase caused higher negative effects in SV1044 hybrid than in Zielo hybrid. The decrease in SV1044 and Zielo hybrid was respectively, 84 % and 71 % in stem length variable (SL) (Figure 4A), 73 % and 62 % in leaf numbers (LN) (Figure



**Figure 4.** Cantaloupe melon plants biometry. Each graphs row is represented by variables, and each graphs column is represented by growth stage and by hybrid factor in isolation. Stem length – SL (A, B, C, D), stem diameter – SD (E, F, G, H), leaf numbers – LN (I, J, K, L), leaf area - LA (M, N, O, P), and shoot dry mass (Q, R, S, T). Markers: (■) vegetative stage, (x) fructification stage, and (+) harvest stage to salinity factor in isolation. Values followed by different lowercase letters are significantly different at P < 0.05 in relation to hybrid factor in isolation.

4l), 88 % and 83 % in leaf area (LA) (Figure 4M), and 89 % and 83 % in shoot dry mass (SDM) (Figure 4Q), comparing values between 0.5 and 5.0 dS m<sup>-1</sup>.

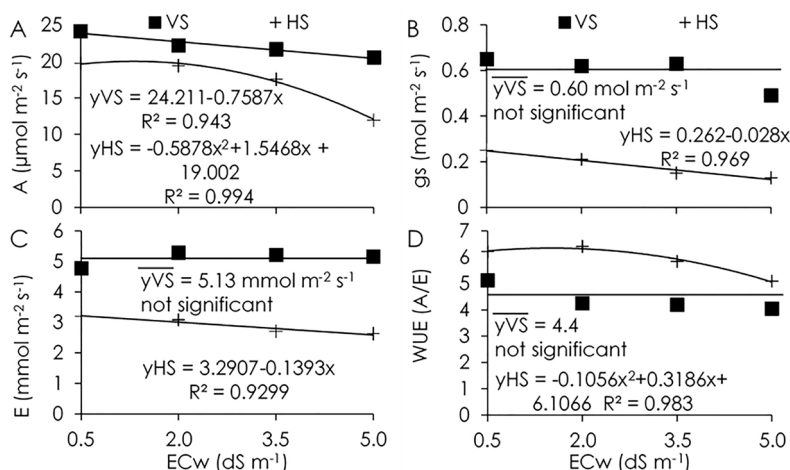
In the fructification stage, SL and LN variables continued to show interaction between factors (ECw x Hyb) (Figure 4B, J), and SV1044 hybrid continued with higher reductions compared to Ziello when the ECw was increased from 0.5 to 5.0 dS m<sup>-1</sup>. The SL decrease was 56 % and 34 % (Figure 4B) and the LN decrease was 66 % and 40 % (Figure 4J) for SV1044 and Ziello, respectively. SV1044 hybrid presented values inferior to Ziello for SL and LN after ECw = 2.97 and 1.68 dS m<sup>-1</sup>, respectively. There was no interaction for the other variables and the ECw caused a proportional decrease in two hybrids. The ECw increase caused reduction of 16 % in SD (Figure 4F), 67 % in LA (Figure 4N) and 64 % in SDM (Figure 4R). Ziello hybrid had higher values of SD (+15 %), LA (+25 %), and SDM (+22 %) than SV1044, regardless ECw (Figure 4H, P, T).

At the end of the crop cycle, in the harvesting stage, there was interaction between factors (ECw x Hyb) for SL variable, with the SV1044 hybrid more affected negatively than the Ziello with the ECw increase. The

reduction in SL was 11.02 % and 6.15 % per ECw unit increase for SV1044 and Ziello, respectively (Figure 4C). There was no interaction between factors for the other variables, and the reduction was 3.89 %, 9.16 %, 12.5 %, and 11.8 %; for SD, LN, LA, and SDM, respectively (Figure 4G, K, O, S) when increasing one ECw unit. Regardless of ECw level, analyzing the hybrid factor in isolation the Ziello hybrid showed values higher than SV1044 for SD, LA, and SDM of 16 %, 35 %, and 25 %, respectively (Figure 4H, P, T).

It was observed that the carbon increment in plants was higher from vegetative to fructification stage than from fructification to harvesting stage, regardless ECw level evaluated (Figure 4D, H, L, P, T). It should be emphasized that the time interval between stages was the same, 21 days.

In relation to gas exchange variables, there was no interaction between factors (ECw x Hyb) for any stage and there was no significant effect by hybrid factor in isolation. There was significant effect to ECw factor on all variables in harvesting stage; however, in vegetative stage ECw only affected CO<sub>2</sub> assimilation rate (Figure 5).



**Figure 5.** Gas exchange in leaves of cantaloupe melon plants. CO<sub>2</sub> assimilation rate – A (A), stomatal conductance – gs (B), leaf transpiration – E (C), and water-use efficiency - WUE (D) to salinity factor in isolation.

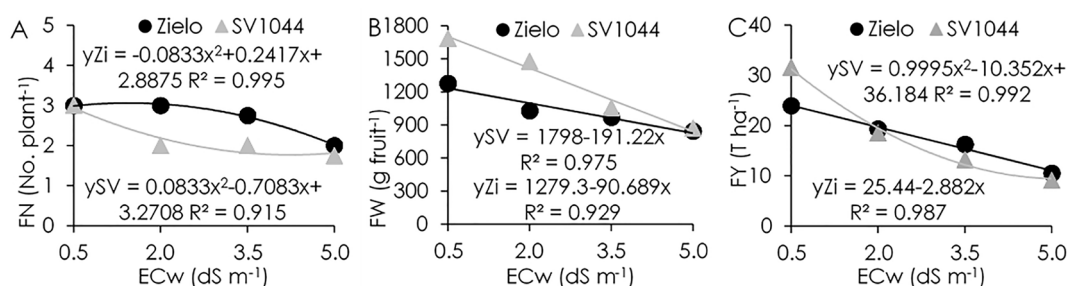
Analyzing the vegetative stage in Figure 5, CO<sub>2</sub> assimilation rate responded inversely proportional to the ECw increase, with 15 % of decrease between the ECw extreme analyzed, the decrease was from 24.1 to 20.5 μmol m<sup>-2</sup> s<sup>-1</sup> (Figure 5A). There was no differentiation between ECw levels for the other gas exchange variables and WUE. Stomatal conductance (gs), leaf transpiration (E), and water-use efficiency (WUE) presented means values of 0.60 mol m<sup>-2</sup> s<sup>-1</sup>, 5.13 mmol m<sup>-2</sup> s<sup>-1</sup> and 4.4 μmol m<sup>-2</sup> s<sup>-1</sup>/mmol m<sup>-2</sup> s<sup>-1</sup>, respectively (Figure 5B, C, D).

In the harvesting stage, all gas exchange variables and WUE were significantly influenced by the ECw increase (Figure 5A, B, C, D). While the CO<sub>2</sub>

assimilation rate (A) decrease was 15 % in the vegetative stage, in the harvesting stage it was 41 %. The A, in the harvesting stage, decreased only after ECw = 1.31 dS m<sup>-1</sup> (Figure 5A). The gs, E and WUE variables, in which remained constant in the vegetative stage, decreased 48 %, 19 %, and 20 %, respectively, in the harvesting stage (Figure 5B, C, D) when ECw was increased.

In relation to fruit production of cantaloupe melon, there was interaction between factors (ECw x Hyb) for all variables: fruit numbers, fruit weight and fruit yield (Figure 6).

The fruit numbers (FN) decrease was more significant in SV1044 than in Ziello hybrid, when the ECw



**Figure 6.** Fruit production of cantaloupe melon plants. Fruit numbers - FN (A), fruit weight - FW (B), and fruit yield - FY (C).

was increased. While the FN decrease started from 1.45 dS m<sup>-1</sup> following a gradual decrease in Ziello hybrid, there was a quadratic decrease from 0.5 to 4.2 dS m<sup>-1</sup> level in SV1044 hybrid. Quadratic equations for FN show coefficient  $a < 0$  for Ziello and  $a > 0$  for SV1044 hybrid, inferring a larger negative effect of the ECw in SV1044 than in Ziello hybrid (Figure 6A).

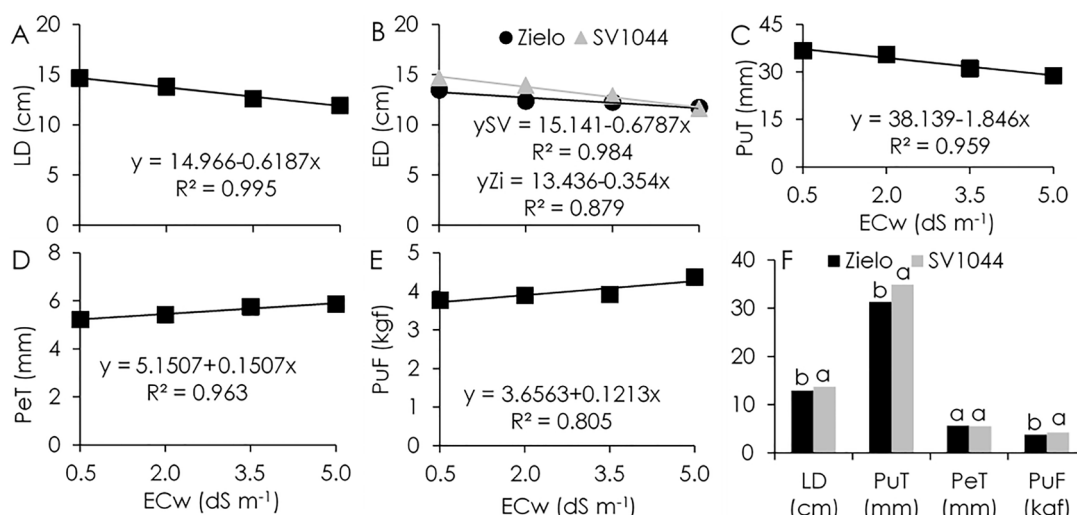
The Ziello hybrid presented lower fruit weight (FW) than SV1044 when cultivated with fresh water (ECw = 0.5 dS m<sup>-1</sup>), 1300 g and 1700 g, respectively. SV1044 hybrid had more significant decrease than Ziello hybrid with the ECw increase. This decrease was 815 g or 48 % for SV1044 and 434 g or 34 % for Ziello, between the lowest and the highest ECw levels applied (Figure 6B).

The final fruit yield (FY) of two hybrids presented decreased with the ECw increase. The FY reduction was linear for Ziello hybrid (-56 %) and quadratic for SV1044

hybrid (-70.3 %), between the lowest and the highest ECw levels. Thus, Ziello presented a reduction of 12.4 % and SV1044 of 16.1 % for each unit ECw increased. The intercept point between Ziello equation and SV1044 equation indicates that SV1044 hybrid had less yield than Ziello after ECw = 1.94 dS m<sup>-1</sup> (Figure 6C).

Hybrids salinity tolerance was considered from the 20 % yield reduction. Thus, the Ziello hybrid tolerated up to ECw = 2.18 dS m<sup>-1</sup> or ECe = 2.77 dS m<sup>-1</sup>, while the SV1044 hybrid tolerated up to ECw = 1.19 dS m<sup>-1</sup> or ECe = 2.06 dS m<sup>-1</sup> (Figure 6C).

In relation to fruit physical quality, there was interaction between factors (ECw x Hyb) for equatorial diameter variable (Figure 7B), but for all others variables each factor, ECw or Hyb, influenced in isolation (Figure 7A, C, D, E, F).



**Figure 7.** Fruit physical quality of Cantaloupe melon. Longitudinal diameter - LD (A), equatorial diameter - ED (B), pulp thickness - PuT (C), peel thickness - PeT (D), pulp firmness - PuF (E). Variables analyzed separately by hybrid factor (F). Marker (■) to salinity factor in isolation. Values followed by different lowercase letters are significantly different at  $P < 0.05$  in relation to hybrid factor in isolation.

The fruit equatorial diameter (ED) decreased 4.5 % in SV1044 hybrid and 2.6 % in Ziello, when was increased one ECw unit (Figure 7B). The ECw x Hyb interaction showed once again that SV1044 hybrid was affected more negatively than Ziello.

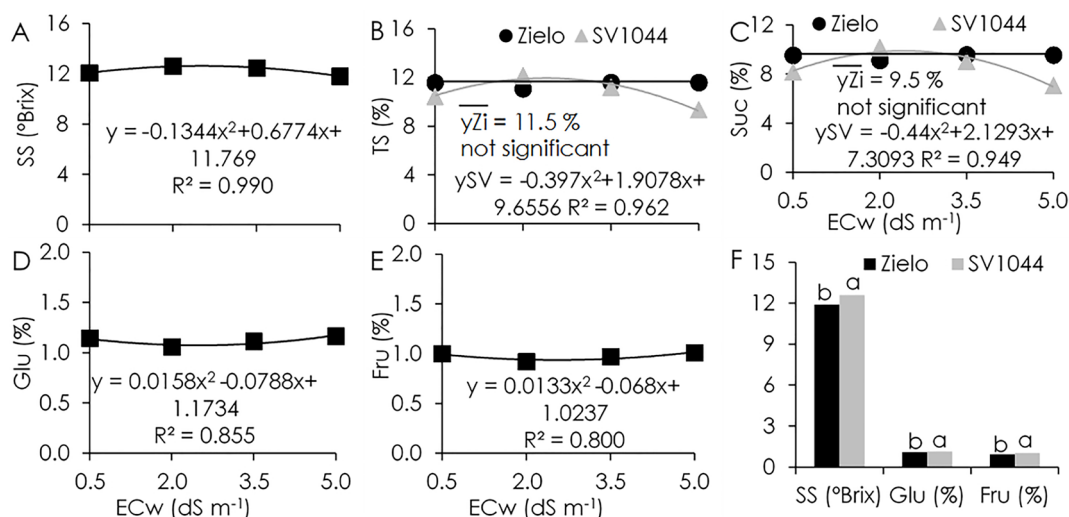
The ECw factor analyzed in isolation indicated

that longitudinal diameter (LD) and pulp thickness (PuT) was inversely proportional to the ECw increase. The LD and PuT reduction was 18.4 % and 21.3 %, respectively, when ECw was increased from 0.5 to 5.0 dS m<sup>-1</sup> (Figure 7A, C). In contrast, peel thickness (PeT) and pulp firmness (PuF) increased directly proportionally with the ECw

increase. The PeT increased 13.5 % (Figure 7D) and the PuF increased 16 % (Figure 7E) when ECw was increased from 0.5 to 5.0 dS m<sup>-1</sup>. The Hyb factor analyzed in isolation indicated that SV1044 had LD (+6.3 %), PuT (+11.5 %), and PuF (+11.9 %) higher than Ziello hybrid (Figure 7F).

In relation to fruit chemical quality, there was interaction between factors (ECw x Hyb) for total sugars

(Figure 8B) and sucrose (Figure 8C) concentration. All other variables were influenced in isolation for each factor, ECw or Hyb, (Figure 8). TS and Suc concentration remained constant in Ziello hybrid, however in SV1044 hybrid there was increase of these concentration until ECw = 2.4 dS m<sup>-1</sup>, after this ECw concentrations decreased (Figure 8B, C).



**Figure 8.** Fruit chemical quality in Cantaloupe melon. Soluble solids – SS (A), total sugars – TS (B), sucrose – Suc (C), glucose – Glu (D), and fructose – Fru (E). Variables analyzed separately by hybrid factor (F). Marker (■) to salinity factor in isolation. Values followed by different lowercase letters are significantly different at  $P < 0.05$  in relation to hybrid factor in isolation.

The ECw factor analyzed in isolation indicated that solids soluble (SS), glucose (Glu) and fructose (Fru) concentration present quadratic answer when ECw was increased. The equational answer for SS concentration was inversely proportional to Glu and Fru concentration. While SS increased until ECw = 2.52 dS m<sup>-1</sup>, with maximum value of 12.6 °Brix (Figure 8A), Glu and Fru concentration decreased until 2.49 dS m<sup>-1</sup> and 2.55 dS m<sup>-1</sup>, respectively (Figure 8D, E). The Hyb factor analyzed in isolation indicated that SV1044 had SS (+5.9 %), Glu (+4.6 %), and Fru (+12 %) higher than Ziello hybrid (Figure 8F).

## Discussion

The soil salt accumulation proportional to the ECw increase is observed due to the sodium and chloride accumulation in soil from irrigation water. Huang et al. (2012), Selim et al. (2013), Tedeschi et al. (2011) and Tedeschi et al. (2017) found soil electrical conductivity of the saturation extract (ECe) in agreement with this study when the ECw was increased.

The reduction in absolute values of plant biometrics variables are associated to the osmotic, toxic, and nutritional effects. Salts accumulation in leaves, mainly Na and Cl, affect the CO<sub>2</sub> assimilation rate, causing inhibition of leaf expansion, consequently reduction in the area destined to the photosynthetic process,

and reduction in the total photoassimilates production (Larcher, 2006). Some studies have shown that plants with high salt tolerance have less growth inhibition (relative growth rate and biomass production) than susceptible plants (Ahmed et al., 2013).

The leaf area reduction is an adaptive mechanism of plants grown under salinity and drought conditions. The transpiration reduction, and consequently reduction in Na and Cl uptake, results in a conservation of water in plant tissues (Taiz & Zeiger, 2013). In this way, inhibition in leaf limb expansion is common characteristic in stressed plants, and in melon this negative effects has been reported (Medeiros et al., 2012). According to our study, Tedeschi et al. (2011) found leaf number reduction when the water salinity was increased. Also, Freitas et al. (2014) and Medeiros et al. (2012) reported decrease in dry mass, -12 % and -14 % for each ECw unit increase.

Na and Cl concentration in leaves were higher in the vegetative stage than in others stages (FS and HS) when the ECw was increased, and this occurred because plants were transpiring equally regardless of ECw. Plants grown at 0.5 or 5.0 dS m<sup>-1</sup>, in vegetative stage, transpired equally, but absorbed more Na and Cl ions when cultivated with water more saline, explained due to the high salts availability. Na and Cl uptake affected negatively CO<sub>2</sub> assimilation rate and sugar production, as



well as caused a lower K uptake through Na competition by the same uptake site in roots. Lúcio et al. (2013) and Tedeschi et al. (2017) reported increase in Na and Cl concentration in leaves, and Sarabi et al. (2017) reported decrease in K concentration in leaves when EC<sub>w</sub> was increased.

At the end of the crop cycle as the exposure of plants to salinity was prolonged, plants had reduction in stomatal conductance and leaf transpiration, possibly to try to absorb less Na and Cl ions and keep water inside the cells. The stomatal conductance reduction may have been reinforced by the K uptake reduction, considering that the stomatal opening is mediated by K ion.

Lúcio et al. (2013) and Cosme et al. (2017) verified gas exchange reduction when the EC<sub>w</sub> was increased. This reduction has been attributed to stomatal and non-stomatal causes, associated with salt toxic effects and the low crop capacity to osmotic adjustment, causing physiological disturbance in plants (Larcher, 2006). The gas exchange reduction can be shaped by the stress level to which plants were submitted (Fernandes et al., 2010).

The increase in fruit numbers per plant induces the competition for assimilates among sinks and cause decrease in both individual fruit weight and soluble solids concentration (Valantin et al., 2006). These results were reported in our study when fruit numbers, fruit weight and soluble solids concentration were analyzed for the Ziolo and SV1044 hybrids. The smaller solids soluble amount in Ziolo than in SV1044 is associated to the higher fruit numbers produced per plant in Ziolo than in SV1044.

Corroborating with results observed in our study, Tedeschi et al. (2011) found significant reduction in fruit numbers and in fruit weight when the EC<sub>w</sub> was increased. Also, Freitas et al. (2014) found decrease of 11 % in Orange Flesh yield and Melo et al. (2011) found decrease of 16 % in Galia yield, for each EC<sub>w</sub> unit increased. Huang et al. (2012), studying melon plants under salinity, reported that the melon tolerance was up to 2.7 dS m<sup>-1</sup> and after this value, there was 12.7 % decrease per EC<sub>e</sub> unit increased. Tedeschi et al. (2011), cultivating melon in the Mediterranean region, observed that the melon salinity tolerated was up to 1.73 dS m<sup>-1</sup> and after this EC<sub>e</sub> value there was 12 % decrease per EC<sub>e</sub> unit increased.

Discussing about fruit physical quality, the increase of peel thickness occurred probably to keep water inside fruit due to the low uptake water in higher EC<sub>w</sub> levels. Another explanation to this thicker peel is that the pulp possibly did not have its ripening complete. Sandri et al. (2007) declare that the thicker peel in fruits

occurs to avoid water loss and to increase the fruit useful life, besides giving greater resistance to mechanical shocks; however, it represents loss of comestible part.

Pectic substances that make up the cell walls influence in the pulp firmness. When the fruit mature, these substances are polymerized and occurs the pulp softening (Chen et al., 2015). The EC<sub>w</sub> increase possibly interfered in pectic substances polymerization increasing pulp firmness in melon fruits of this study. Cosme et al. (2017) reported that increasing EC<sub>w</sub> levels the pulp firmness increased directly proportional.

Discussing about fruit chemical quality, the positive linearity between soluble solids and EC<sub>w</sub> increase is associated with the nutrient concentration effect due to the low water supply to the fruit. Huang et al. (2012) and Tedeschi et al. (2011) observed positive linear effect on soluble solids of melon fruits when EC<sub>w</sub> was increased. European and North American market, to import melon fruits, require at least 10 °Brix of solids soluble at harvest week. All fruits harvested in our study have presented the solids soluble minimum required for export, but other quality characteristics should be taken into account.

Chitarra & Chitarra (2005) explain that solids soluble concentrations are indirect measure of sugars, because this component represents between 74 % and 87 % of solids soluble in cantaloupe melons. Glucose and fructose contribute almost 100 % of the soluble sugar concentration at the initial stage of fruit development; however, at the final of ripening stage, sucrose reaches 50 % of soluble sugars (Yativ et al., 2010).

## Conclusions

Salts concentration increase in irrigation water, mainly Na and Cl ions, cause salts accumulation in soil and in leaves of melon plants, causing reduction in plant growth and consequently reduction in fruit production and quality. These reductions are mediated by specific toxic effect, nutritional imbalance such as reduction of K uptake, as well as reduction in water absorption (osmotic effect) evidenced by the reduction in gas exchange and water-use efficiency.

The Ziolo hybrid is tolerant to salinity up to EC<sub>w</sub> = 2.18 dS m<sup>-1</sup> and the SV1044 hybrid up to EC<sub>w</sub> = 1.19 dS m<sup>-1</sup>, considering up to 20 % yield reduction. Fruits have quality requirements imposed by the international market up to the salinity levels tolerated. Although fruits have minimum soluble solids concentration required to exportation in all salinity levels, after the levels tolerated there is reduction in fruit size and the fruit pulp is more rigid and has less comestible part.

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**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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