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Physiological Aspects of Melon (*Cucumis melo* L.) as a Function of Salinity

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Abstract

This study evaluated the effect of saline water irrigation (4.5 dS m^{-1}) on growth, gas exchange and mineral nutrient content in eight melon accessions and two cultivars classified as tolerant (Sancho) and susceptible (Caribbean Gold) to salinity. Results showed saline water irrigation reduced stomatal conductance, which consequently decreased transpiration and photosynthesis. Also, plants became more efficient in water use under salinity and increased K^+/Na^+ in leaves as a mechanism to mitigate the ionic stress caused by Na^+ and Cl^-. Moreover, the accessions responded differently from cultivars to saline water irrigation. However, we found accessions more efficient in water use, with more K^+/Na^+ content and higher photosynthesis rate than Sancho under saline and non-saline water irrigation. Due to these traits, these accessions were more productive than Sancho under salinity.

Keywords Abiotic stress · *Cucurbitaceae* · Growth · Photosynthesis · Saline water irrigation

Introduction

Brazil is one of the largest producers of fruits and vegetables in the world. Among the most appreciated and produced vegetables in the north-east semiarid region, melon (*Cucumis melo* L.) stands out. Melon cultivation is consolidated in the north-east region, especially in the states of Rio Grande do Norte and Ceará, thanks to good adaptation to climatic conditions and efficient control of fruit flies, resulting in high quality with 26% higher productivity in the 2018 harvest (August to November) compared to the years 2017/2018 (Melão 2018; Secex 2018).

Success in melon production depends on the use of irrigation production and the quality and quantity of water. The efficient use of water is becoming increasingly important due to the scarcity of water resources in the region (Medeiros et al. 2012a). Due to low rainfall, water of inferior quality such as saline has been used by growers, due to its high availability in this region, ease of access (shallow well water) for reduced cost and potential use for irrigation, although the high level of salinity, electrical conductivity (EC) above 2.2 dS m^{-1}, may limit crop yield, leading to the salinization of soils (Porto Filho et al. 2011; Dias et al. 2011; Freitas et al. 2014; Kim et al. 2016). Due to the economic importance of

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melon in the region of Mossoró-RN, technicians and growers need up-to-date information to enable them to obtain high production, and to verify the behaviour of this crop in relation to the salinity level of irrigation water (Medeiros et al. 2012b). In this respect, considering the economic importance of melon, understanding crop mechanisms in relation to abiotic stresses such as salinity is a challenge that requires genotypes with greater tolerance, aiming to increase agricultural production.

The literature has shown that using saline water has more severe effects on initial vegetative development by reducing leaf area and dry weight of leaves and stems as the electrical conductivity of irrigation water is increased (Dias et al. 2015; Morais et al. 2019). In addition, salinity compromises all processes of the physiological apparatus, from reducing seed germination to the operation of more complex systems such as photosynthesis, stomatal conductance, transpiration, leaf area and total dry mass (Secco et al. 2010; Fernandes et al. 2010; Sarabi et al. 2017; Morais et al. 2018). Melon presents a moderate tolerance to salinity due to its capacity to compartimentalisation of ions in the vacuole of the plant cell (Secco et al. 2010). However, melon plants deviate energy from growth to exclude Na^+ and Cl^- and for the synthesis of compatible solutes, such as proline and citrulline, to adjust the osmotic potential inside the cell (Sarabi et al. 2017). Also, under salinity stress conditions, plants showed depression in leaf water content, membrane stability, chlorophyll and carotenoid content, stomata and trichome density, leaf area, biomass, leaf and stem K^+ concentration. Exposure to environmental stresses, can increase reactive oxygen species (ROS) production and lead to oxidative stress, what causes damage and affects metabolic functions at the site in the cell where it accumulates (Morais et al. 2019). Phenological stage, duration and intensity of the stress and genotype are factors that may influence the response of the plant (Ghelfi et al. 2011).

Some melon genotypes show salinity tolerance, as they possess more efficient mechanisms of stress protection to survive, which allows the cultivation of this species in salinised areas (Kuşvuran et al. 2012). In view of the need to search for more resistant and salinity-tolerant materials, studies are needed to enable the use of rustic materials for genetic improvement. According to Araújo et al. (2016), it is of great importance to increase the role of genotypes with salinity tolerance potential, and with the capacity to offer high yields even with the use of inferior water, such as saline. Thus, this work aimed to evaluate the morphological and physiological responses of melon accessions under saline water irrigation.

Materials and Methods

Experimental Area and Plant Material

The experiment was conducted in August 2017 under greenhouse conditions in the Agrarian Sciences Centre (CCA), Universidade Federal Rural do Semi-Árido (UFERSA, Mossoró, Rio Grande do Norte State, Brazil, 5°11′31″ S, 37°20′40″ W). The climate of the region, according to the Köppen classification is BSwh, that is dry and very hot with two seasons: a drought from June to January and a rainy season from February to May, presenting a 27 °C average annual temperature, 673 mm average annual rainfall, 68% relative humidity and 241.7 h per month brightness (Carmo Filho and Oliveira 1989).

The experiment was carried out in a greenhouse with an arched ceiling, coated with low density polyethylene film (150 µm thick), with protected black screen panels with 50% shading. The experimental design involved randomised blocks in a factorial scheme (2×10) with eight replicates totalling 160 bags of known capacity. In the first factor, the electrical conductivity of the irrigation water were allocated (4.5 dS m^{-1} as saline water and 0.5 dS m^{-1} as control), and the second factor was the eight melon accessions from the germplasm bank from UFERSA (A07, A14, A17, A24, A24, A34, A35, A36 and A39, Table 1) and two cultivars (Sancho and Caribbean Gold).

Two seeds were placed in black polyethylene bags with 5 L capacity, which were filled with Golden Mix® coconut (*Cocos nucifera* L.) fibre (6.0 ± 0.3 pH, 0.5 dS m^{-1} electrical conductivity, 85 kg m^{-3} density, and 500 (w/w) relative water content). To fill the bags, 25% of the volume was filled with granite gravel by adding it to the base, completing the remaining volume with 75% of coconut fibre (totalling 5 L of bag volume). After seven days from

Table 1 Botanical classification of melon cultivars and accessions used in the experiment

Materials	Botanical group
A07	*Cantaloupensis*
A14	*Cantaloupensis*
A17	*Conomon*
A24	*Cantaloupensis*
A34	*Cantaloupensis*
A35	Not identified
A36	*Cantaloupensis*
A39	*Cantaloupensis*
Caribbean Gold	*Cantaloupensis*
Sancho	*Inodorus*

Table 2 Chemical characteristics of the irrigation water used in the experiment

Chemical characteristics	Unit	Water well	Supply
Electrical conductivity	dS m^{-1}	4.5	0.50
pH	–	7.00	7.00
K^+	mmolc L^{-1}	2.84	0.25
Na^+	mmolc L^{-1}	15.38	4.44
Ca^{2+}	mmolc L^{-1}	22.30	1.00
Mg^{2+}	mmolc L^{-1}	18.50	0.90
Cl^-	mmolc L^{-1}	26.40	2.40
CO_3	mmolc L^{-1}	0.00	0.00
HCO_3	mmolc L^{-1}	1.70	3.40
Sodium adsorption ratio	–	3.4	4.60
Hardness	mg/L	2040	95.00
Cations	mmolc L^{-1}	59	6.60
Anions	mmolc L^{-1}	28.1	6.50

Table 3 Fertilisers used as a source of macronutrients and micronutrients for the preparation of the nutrient solution

Fertilisers	Composition
Magnesium sulfate ($MgSO_4$)	460 g
Potassium sulfate (K_2SO_4)	23.5 g
Potassium chloride ($KClO_3$)	30.8 g
Potassium nitrate (KNO_3)	570 g
Calcium nitrate ($Ca(NO_3)_2$)	842 g
Monoammonium phosphate ($NH_4H_2PO_4$)	98 g
Iron Sulphate ($FeSO_4$)	13.9 g
EDTA—Sodium ($C_{10}H_{14}N_2Na_2O_8$)	13.9 g
Boric acid (H_3BO_3)	3.10 g
Manganese Sulfate ($MnSO_4$)	1.70 g
Zinc sulfate ($ZnSO_4$)	0.22 g
Copper sulfate ($CuSO_4$)	0.75 g
Ammonium molybdate $(NH_4)6Mo_7O_{24}$ $4H_2O$	1.25 g

Composition of the fertilisation of Hoagland and Arnon (1950) in 100% diluted in 1000L

sowing, thinning was done leaving only one plant per bag when the second leaf was complete.

The water used for saline treatment came from an artesian well belonging to the eastern campus of the UFERSA, with chemical characteristics as described in Table 2. For the control treatment, water from the public supply was used, adding the nutrient solution. After the water was collected, it was conditioned to prepare the nutrient solution and then used for daily irrigations with the pre-established electrical conductivity.

The distilled water used for the preparation of the stock solutions was obtained by the reverse osmosis process with an electrical conductivity of 0.06 dS m^{-1}. The fertilisers were composed of macronutrients and micronutrients weighed separately in an analytical balance (precision 0.0001 g) and dissolved individually in 1 L of distilled water, after which it was conditioned in amber glass for the composition of the nutrient solution according to the proposed methodology of Hoagland and Arnon (1950) using 50% of its composition (Table 3).

Before the addition of the macro and micronutrients, the electrical conductivity was adjusted as pre-established for the treatments and monitored weekly with a conductivity metre and a sample of 100 mL solution withdrawn from the main reservoir of each treatment for monitoring.

Irrigation was performed by the manual method using two independent containers to apply the two levels of the electrical conductivity of the irrigation water. These systems were composed of two glass fibre boxes with a capacity of 150 L each. The applications of the treatments were carried out with a vessel of known capacity until saturation of the substrate was reached (200 mL). The saturation was confirmed when the process of draining the bags began. The application of saline water was carried out initially after the formation of the third complete leaf of the melon until reaching the initial flowering stage of the plant, in order to carry out the evaluations and determine the growth and development of the melon at a later stage.

The plants were vertically guided and kept on a single stem with the use of wooden sticks up to 1.40 m from the sack. Phytosanitary control was carried out according to the needs of the crop, with curative applications of phytosanitary products between 10 and 35 days after planting to control green aphid (*Myzus persicae*), thrips (*Thrips tabaci*) and white fly (*Bemisia tabaci*). After the flowers were opened, the evaluations were carried out respecting each stage of the development of each material, since they presented different cycles.

Physiological Attributes

Physiological attributes were measured on the seventh fully expanded leaf from the apex of the plant at 25 and 35 days after transplanting (DAT) when flowers reached anthesis. Analyses were performed on two different days because of melon accessions flowering at different times. Thus, due to heterogeneity, some plants were evaluated at 25 days, and the remaining plants were analysed at 35 days.

Analyses were performed using a portable infrared radiation photosynthesis analyser (Walz-GFS-3000 portable photosynthesis system) at 9:00–11:00 a.m. on sunny days without cloud cover. The photon flux (PPFD) maintained in the Infrared Gas Analyser (IRGA) chamber was 1200 µmol m^{-2} s^{-1} at the 25 and 35 DAT evaluations. Net photosynthesis (*A*), leaf transpiration (*E*), stomatal conductance (*gs*), internal CO_2 concentration (*Ci*) and water use

efficiency ($WUE = A/E$) were measured. During the measurements, the ambient mean temperature was 32 °C and leaf temperature was 26 °C along with the density of the external medium.

Growth and Accumulation of Dry Weight

The growth and accumulation of dry weight was verified between 25 and 40 days after sowing and opening of the floral buds in all plants, cutting them close to the substrate. In these plants, the leaf area (LA) was calculated by the product of leaf length and width. The number of leaves was counted by counting all the leaves of each plant. The height of the plants was measured with a tape measure from the base of the plant to the pointer of each plant and the results were expressed in cm. The stem diameter was measured using a digital calliper and the results expressed in mm using the base of the plant as reference. Fresh biomass was determined by weighing roots, stems and fresh leaves separately and the results expressed in g. The dry biomass was determined by weighing roots, stems and leaves separately, obtained after oven drying with forced-air circulation at 60 °C for 72 h.

Concentration of Macronutrients and Micronutrients

The extracted and exported contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and chlorine (Cl) were determined in roots, stems and leaves after opening the flowers of each material. All the plants of the parcel were collected; later the plants were oven dried at 60 °C and ground in a knife mill. In the extracts obtained by digestion with sulfuric acid, the elements N, P, K, Ca and Mg were determined. For the Na and Cl elements, these were extracted with nitric acid. Ca and Mg were determined by atomic absorption spectrophotometry; the P content was determined by the reduction of phosphomolybdate by Vitamin C; the Na and K contents were determined by emission in flame photometry. For the determination of total N content, the samples were digested with concentrated H_2SO_4 and then determined by the Nessler colorimetric method. The chemical analyses of the nutrient contents were carried out at the Soil and Plant Laboratory (LASAP), belonging to the UFERSA. The ionic ratios were determined by the K/Na ratio of roots, stems and leaves.

Production Efficiency Index

The classification of the materials was carried out according to the index proposed by Fageria (1985), where the classification can be made as tolerant genotypes having an efficiency index greater than 1.0; moderately tolerant genotypes related to indices between 0.5 and 1.0; and susceptible genotypes comprising efficiency ratios between 0 and 0.5, using the formula:

$$\mathrm{PEI} = \frac{\mathrm{PHSL}}{\mathrm{APHSL}} \times \frac{\mathrm{PLSL}}{\mathrm{APLSL}}$$

where PEI is the production efficiency index, PHSL is the production under high salinity level, APHSL is the average production under high salinity level, is the PLSL is the production under low salinity level, and APLSL is the average production under low salinity level.

Statistical Analysis

The data were submitted to analysis of variance and the means were compared by the Scott–Knott test ($p < 0.05$) using ASSISTAT 7.7 beta software (Silva and Azevedo 2009). The relationships among the measured attributes were also evaluated by Pearson correlation analysis. The data collected were analysed by multivariate analysis using principal component analysis (PCA) and cluster analysis (CA) by using a correlation matrix. As a criterion for extracting the major principal components, an eigenvalue greater than 1.0 was adopted. The PCA results were used to construct two-dimensional dispersion plots for a graphical overview of the relationships between the melon materials according to PC1 and PC2 using Statistica software, version 10.0.

Results

Physiological Attributes

A significant interaction ($p < 0.01$) between the melon plants and irrigation water was observed for the physiological attributes (Table 4). The effect of electrical conductivity of irrigation water on physiological attributes are presented in Table 5. Salinity did not affect any physiological attributes only in Sancho. Salinity just affected *E* in A39 and *gs* in Caribbean Gold. A36 and Caribbean Gold behaved physiologically similarly in relation to *Ci* and *WUE* under saline water irrigation. However, A36 decreased *A* (32%) while Caribbean Gold increased *gs* (213%) due to salinity. Like A36 and Caribbean Gold, A39 was one of the plants with higher *A*, *Ci* and *WUE*, besides showing highest *E* under salinity. A17 was the plant with most physiological attributes affected by salinity; only *E* did not alter due to saline water.

Among the studied melon plants, highest *E* was observed in A39, *gs* in A24, A36, Caribbean Gold and Sancho, *A* in A17, A24, A34, A35, A36, A39 and Caribbean Gold, *Ci* in A07, A17, A36, A39 and Caribbean Gold, and *WUE* in A07, A17, A34, A36 and Caribbean Gold.

Table 4 Analysis of variance for physiological attributes in melon plants (*Cucumis melo* L.) grown under saline water irrigation

SV	DF	Mean square				
		E	*gs*	*A*	*Ci*	*WUE*
Block	7	0.009**	0.02^{ns}	3.35^{ns}	955.56^{ns}	4.98^{ns}
Material (M)	9	1.79**	0.08**	79.52**	4323.33**	28.53**
Salinity (S)	1	0.22^{ns}	0.002^{ns}	0.46^{ns}	7606.70*	16.04^{ns}
M x S	9	1.04**	0.14**	30.79**	7401.13**	53.83**
Error		0.13	0.02	5.66	1317.21	7.40
Mean		1.49	0.44	9.95	220.70	7.20
CV%		24.45	36.81	23.92	16.44	37.76

SV source of variation, *DF* degrees of freedom, *E* Transpiration, *gs* stomatal conductance, *A* net photosynthesis, *Ci* internal CO_2 concentration, and *WUE* water use efficiency

*, **: significant at $p < 0.01$ and $p < 0.05$, respectively, according to the F test; ns: non-significant

Table 5 Effect of saline water irrigation on transpiration (*E*), stomatal conductance (*gs*), net photosynthesis (*A*), internal CO_2 concentration (*Ci*) and water use efficiency (*WUE*) in melon plants (*Cucumis melo* L.)

Material	*E* (mmol H_2O m^{-2} s^{-1})		*gs* (mmol m^{-2} s^{-1})		*A* (µmol CO_2 m^{-2} s^{-1})	
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}
A07	0.99dB	1.43bA	0.39bB	0.67aA	7.92bA	8.93bA
A14	1.04dA	0.91dA	0.44bA	0.50aA	4.62cB	7.15bA
A17	1.30cA	1.62bA	0.27bB	0.50aA	12.03aA	8.08bB
A24	1.64bA	1.56bA	0.57aA	0.31bB	9.35aB	12.03aA
A34	1.55cA	1.25cA	0.46bA	0.48aA	11.43aA	6.83bB
A35	1.88bA	0.66dB	0.42bA	0.35bA	11.57aA	8.72bB
A36	1.47cB	1.94aA	0.55aA	0.50aA	10.57aB	13.12aA
A39	2.27aA	1.83aB	0.36bA	0.45aA	11.51aA	13.01aA
Caribbean Gold	1.98bA	1.89aA	0.47aA	0.15cB	13.67aA	12.85aA
Sancho	1.16dA	1.45bA	0.57aA	0.50aA	7.36bA	8.18bA

	Ci (mmol CO_2 mol^{-1})		*WUE* (µmol CO_2 /mmol H_2O)	
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}
A07	237.23aA	246.91aA	8.33aA	6.45bA
A14	251.16aA	190.04bB	4.52bB	7.88bA
A17	209.08bB	259.48aA	10.11aA	5.00bB
A24	185.63bB	266.10aA	5.69bA	8.06bA
A34	159.09bB	213.95bA	7.43aA	5.66bA
A35	197.20bA	220.07bA	6.50bB	14.86aA
A36	237.68aA	208.53bA	7.80aA	7.14bA
A39	229.75aA	217.12bA	5.08bA	7.30bA
Caribbean Gold	241.03aA	230.97bA	7.10aA	6.82bA
Sancho	190.22bA	222.76bA	6.30bA	6.02bA

Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$)

Growth Parameters

Except for number of leaves (NL) and stem diameter (SD), saline water irrigation significantly affected melon growth components ($p < 0.05$) (Table 6). Among plants, NL varied from 21.12 (Sancho) to 82 (A35) (Table 7), while SD was quite similar, just A39, Caribbean Gold and Sancho presented higher values.

Only A17 increased shoot height (SH) (+ 148%) under saline water treatment, a response not observed in the other

Table 6 Analysis of variance for growth parameters in melon plants (*Cucumis melo* L.) grown under saline water irrigation

SV	DF	Mean square									
		NL	SD	PH	LA	RFW	RDW	SFW	SDW	LFW	LDW
Block	2	608.06*	2.51**	7843.46*	146,052.21^{ns}	2.86^{ns}	0.05^{ns}	529.52^{ns}	2.99*	256.16^{ns}	6.92**
Material (M)	9	4826.14**	2.02**	16,917.89**	1,916,715.49**	50.09**	0.25**	3431.61**	18.90**	943.27**	2440**
Salinity (S)	1	41.00^{ns}	0.09^{ns}	4584.95^{ns}	1,525,470.73**	1.50**	0.35**	2096.34**	0.23^{ns}	1857.83**	3.66^{ns}
M x S	9	433.90^{ns}	0.42^{ns}	13,936.28**	479,146.57**	22.77**	0.11**	1264.63**	2.42*	413.94**	7.30**
Error	38	277.01	0.53	2953.68	83,786.06	4.11	0.04	255.34	1.14	144.60	2.44
Mean		38.84	4.21	188.28	1147.20	5.54	0.55	59.89	3.82	39.94	4.68
CV%		38.79	17.38	28.86	25.23	36.59	35.96	26.68	27.92	30.10	33.41

SV source of variation, *DF* degrees of freedom, *NL* number of leaves, *SD* stem diameter, *PH* plant height, *LA* leaf area, *RFW* root fresh weight, *RDW* root dry weight, *SFW* stem fresh weight, *SDW* stem dry weight, *LFW* leaf fresh weight, *LDW* leaf dry weight

*, **significant at $p < 0.01$ and $p < 0.05$, respectively, according to the F test; ns: non-significant

plants. In contrast, leaf area (LA) reduced by 44% in A35 due to salinity (Fig. 2). A07, A14, A35 and A39 presented the highest LA (Table 7).

Root fresh weight (RFW) and root dry weight (RDW) increased under saline water treatment in A17 and A39 accessions, with 58% and 77%, and 62% and 100% increments, respectively. On the other hand, RFW decreased by 43% in A35 and by 31% in Sancho (Table 7).

A14, A36, A39 and Sancho had the highest stem fresh weight (SFW) and stem dry weight (SDW) under saline water. In contrast, A35 and A39 reduced SFW by 54% and 23% and SDW by 30% and 20%, respectively (Table 7).

Under saline water treatment, leaf fresh weight (LFW) did not differ among materials under saline water, but A14, A35 and A36 reduced by 20%, 42% and 29%, respectively, compared to non-saline water treatment. A14, A35, A36, A39 and Sancho showed the highest leaf dry weight (LDW) among materials, but A35 reduced by 41%.

Mineral Nutrient Content

Roots

The mineral nutrient content in roots, stems and leaves varied significantly ($p < 0.05$) among melon plants under saline water treatment (Table 8). Saline water irrigation increased the N content in roots of A07, A14, A17, A34 and A35 by 162%, 45%, 163%, 55% and 107%, respectively, while it was decreased by 30% in A24, as compared to the non-saline water (Table 11). Additionally, it increased Ca^{2+} content by 254%, 30% and 24% in A07, A34 and A39, and Na^{+} content by 106% and 45% in A24 and Sancho, respectively (Table 9). In contrast, saline water did not affect P and K^{+} contents in roots, but major concentrations were found in A07, A14, A17, A24 and A34, and in A14, A17 and A24, respectively. A14 and A36 were the plants that accumulated most Mg^{2+} and Cl^{-} in the roots. However, under saline water irrigation, roots of all plants accumulated 37% and 44% more Mg^{2+} and Cl^{-}, respectively.

Stems

In stems, all plants accumulated more Ca^{2+} (+32%), Mg^{2+} (+60%), Na^{+} (+29%) and Cl^{-} (+30%) and less N (-11%) and K^{+} (-14%) under saline water treatment (Table 10). However, only A14 and A17 increased P content (by +50% and +1017%, respectively) when irrigated with saline water (Table 11). A36 was the plant that most accumulated Na^{+} and Cl^{-} in stems, while A39, although it accumulated more Na^{+} in the stems, was one of the plants that accumulated less Cl^{-} in this organ.

Leaves

In leaves, all plants accumulated more Ca^{2+} (+31%) and Cl^{-} (+61%) when irrigated with saline water (Table 10). A07, A14, A24, A34, A39, Caribbean Gold and Sancho accumulated 459%, 492%, 553%, 523%, 1064%, 471% and 560% more K^{+}, respectively, in leaves under saline water irrigation compared to non-saline. Similarly, A17 accumulated more Mg^{2+} (+47%), while A07 and A35 accumulated more Na^{+} (+59 and +66%, respectively). In contrast, A34, A35, Caribbean Gold and Sancho accumulated less Mg^{2+} (−66%, −64%, −71% and −74%, respectively) under saline water irrigation. The P content in leaves was not affected by salinity, but A07 was that most accumulated P while A35 and Caribbean Gold had less accumulated P in leaves (Table 12).

Nutrient accumulation in the roots was, in decreasing order: K > N > Na > P > Ca > Mg > Cl; in stems was N > K > Na > P > Ca > Mg > Cl; and in leaves was N > K > Ca = Na > Mg > Cl (Table 8).

Table 7 Effect of saline water irrigation on growth variables of melon (*Cucumis melo* L.) cultivars and accessions

Material	Number of leaves	Stem diameter (mm)	Shoot height (cm)		Leaf area (cm2)	
			4.5 dS m−1	0.5 dS m−1	4.5 dS m−1	0.5 dS m−1
A07	35.93b	3.94b	200.37bA	221.62aA	1203.99aA	1203.75cA
A14	48.37b	4.13b	223.12bA	251.00aA	1164.60aA	1409.42cA
A17	28.50c	4.21b	284.12aA	114.25bB	934.95bA	1015.20dA
A24	34.25b	3.51b	140.62cA	131.87bA	816.77bA	565.92eA
A34	38.75b	4.27b	188.87cA	179.37aA	886.50bA	945.05dA
A35	82.68a	4.04b	158.00cA	189.87aA	1338.69aB	2416.20aA
A36	35.18b	4.14b	205.50bA	220.87aA	920.17bA	1088.12dA
A39	40.12b	4.73a	178.00cA	197.12aA	1363.32aA	1628.32bA
C. Gold	23.62c	4.50a	142.75cA	129.93bA	821.25bA	878.07dA
Sancho	21.00c	4.63a	215.00bA	193.37aA	1045.38bA	1298.44cA
	Leaf fresh weight (g)		Stem fresh weight (g)		Root fresh weight (g)	
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}
A07	30.70aA	37.15cA	54.60bA	60.33cA	4.18cA	3.76bA
A14	40.36aB	52.48bA	66.45aA	75.57bA	5.36bA	5.18bA
A17	38.08aA	31.86cA	46.98bA	43.01dA	6.24bA	3.93bB
A24	35.74aA	30.38cA	46.78bA	37.24dA	4.33cA	3.53bA
A34	30.54aA	34.58cA	48.69bA	47.20dA	5.97bA	4.68bA
A35	39.78aB	68.97aA	44.94bB	96.67aA	5.87bB	10.38aA
A36	33.72aB	47.44bA	62.55aA	60.38cA	4.52cA	4.31bA
A39	43.35aA	48.00bA	68.96aB	90.46aA	10.24aA	6.32bB
Caribbean Gold	31.54aA	33.51cA	44.35bA	44.62dA	3.64cA	3.51bA
Sancho	41.56aA	49.14bA	78.39aA	79.59bA	6.00bB	8.82aA
	Leaf dry weight (g)		Stem dry weight (g)		Root dry weight (g)	
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}
A07	3.48bA	3.88cA	3.65bA	3.58bA	0.46bA	0.40bA
A14	5.37aA	5.58bA	4.85aA	4.70aA	0.57bA	0.58aA
A17	3.93bA	3.30cA	3.03cA	2.75bA	0.55bA	0.31bB
A24	4.10bA	3.33cA	2.42cA	1.36cA	0.39bA	0.34bA
A34	4.23bA	3.95cA	3.80bA	3.05bA	0.61bA	0.58aA
A35	5.57aB	9.56aA	3.59bB	5.10aA	0.64bA	0.69aA
A36	4.85aA	4.69bA	4.38aA	4.60aA	0.66bA	0.55aA
A39	5.05aA	5.37bA	4.67aB	5.85aA	1.04aA	0.52aB
Caribbean Gold	3.73bA	3.66cA	2.69cA	2.78bA	0.49bA	0.46bA
Sancho	4.97aA	4.98bA	4.77aA	4.86aA	0.58bA	0.63aA

Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$)

Production Efficiency Index

The production efficiency index (PEI) and classification of all studied melon plants for tolerance to salinity (Fageria 1985) are shown in Table 13. Only A24 was classified as susceptible to salinity. The other plants were classified as tolerant or moderately tolerant to salinity based on the PEI.

Pearson Correlation Analysis

Correlations between physiological and growth parameters of melon plants grown under saline and non-saline water are presented in Table 14. *E* was positively correlated with *A* and negatively correlated with *gs*. The other physiological attributes did not correlate. Among growth parameters, positive correlations were also observed.

Table 8 Analysis of variance for mineral nutrient content in different organs of melon plants (*Cucumis melo* L.) grown under saline water irrigation

Organ	SV	DF	Mean square						
			N	P	K	Ca	Mg	Na	Cl
Root	Block	2	17.61 ^{ns}	0.53 ^{ns}	29.76 ^{ns}	0.10 ^{ns}	0.007 ^{ns}	0.77 ^{ns}	465.38 ^{ns}
	Materials	9	36.56**	4.16**	104.55**	1.66**	0.10**	36.40**	6181.81**
	Salinity	1	100.88**	3.58 ^{ns}	8.06 ^{ns}	0.59**	0.17**	21.84**	4851.00**
	M x S	9	37.99**	6.95**	50.78 ^{ns}	0.15*	0.009 ^{ns}	4.05*	479.07 ^{ns}
	Error	38	5.61	0.87	28.44	0.05	0.004	1.59	292.27
	Average		12.08	3.87	25.51	1.31	0.32	6.30	49.22
	CV%		19.61	24.12	20.90	17.80	21.11	20.03	34.73
Stem	Block	2	11.55 ^{ns}	0.05 ^{ns}	2.70 ^{ns}	0.02 ^{ns}	0.04 ^{ns}	0.65 ^{ns}	1.42 ^{ns}
	Materials	9	16.26 ^{ns}	32.14**	24.57**	2.33**	0.88**	42.19**	7188.41**
	Salinity	1	78.43*	6.76 ^{ns}	24.87**	4.06**	2.80**	36.19**	3588.26*
	M x S	9	7.70 ^{ns}	7.07**	0.71 ^{ns}	0.24 ^{ns}	0.08 ^{ns}	2.06 ^{ns}	293.34 ^{ns}
	Error	38	12.14	1.70	1.35	0.14	0.05	1.31	609.98
	Average		19.32	5.27	8.28	1.89	0.93	6.05	59.76
	CV%		18.03	24.75	14.07	20.15	24.16	18.95	41.32
Leaf	Block	2	19.70 ^{ns}	3.06 ^{ns}	0.40 ^{ns}	1.35 ^{ns}	0.08 ^{ns}	0.06 ^{ns}	2443.40 ^{ns}
	Materials	9	42.62 ^{ns}	23.26**	619.92**	20.82**	1.46**	1.74**	5281.88**
	Salinity	1	110.97 ^{ns}	0.77 ^{ns}	7859.28**	59.68**	3.55**	1.53 ^{ns}	24,745.70**
	M x S	9	27.44 ^{ns}	2.38 ^{ns}	418.38**	5.58 ^{ns}	1.34**	1.01*	2383.77 ^{ns}
	Error	38	27.54	1.93	14.06	2.38	0.11	0.44	1556.50
	Average		38.40	4.98	24.23	7.50	1.30	3.37	86.89
	CV%		13.65	27.93	15.47	22.58	26.47	19.84	45.40

SV source of variation, *DF* degrees of freedom, *ns* non-significant

**, *Significant at $p < 0.01$ and $p < 0.05$, respectively, according to the F test

Principal Component Analysis

Principal components explained 86.33% of the total variance among melon plants under saline water treatment (Table 15). For each factor, a load value above 1.0 was considered significant. The scores and loading plots of PCA on melon plant parameters are presented in Figs. 1 and 2, respectively. The first (PC1) and second (PC2) major components accounted for 59.6% of the total variance and thus, accounted for most of the effect of saline water on physiological and growth parameters of melon cultivars and accessions.

Discussion

Salinity is one of the main factors affecting productivity of plants. In the present study, decreased *E* under saline stress conditions may be attributed to partial stomatal closure associated with the osmotic effect and ionic toxicity on plant metabolism (Neves et al. 2009). Thus, a 30% decrease in A07 *E* and 25% in A36 *E* (Table 5) can be explained because salt stress decreases *gs*. Additionally, a decrease in A07 *E* is due to higher K^+/Na^+ in roots and stems (Table 16). *E* and *gs* rates are the first mechanisms controlling stomatal closure and affects plant growth, as it limits the production of phytomass, due to the low supply of CO_2 (Ashraf 2010). Stomata not only act as the prime exit for water loss, but also function as entry channels for atmospheric CO_2 required for photosynthesis (Ahammed et al. 2020). Stressed plants reduce *E* and *gs* to maintain or increase *WUE* caused by the delay between root uptake and water vapour release since stomatal closure is a strategy to avoid dehydration (Ferraz et al. 2012). Therefore, an increase in the K^+/Na^+ ionic ratio in roots and stems may act as a stress tolerance mechanism, since high Na^+ content disturbs water uptake besides damaging the photosynthetic apparatus (Morais et al. 2019). K^+, in contrast, plays key roles in plant processes, such as in enzyme activation, protein synthesis, photosynthesis, osmoregulation, and acts directly on stomatal opening and closing (Silva et al. 2011).

The reduction in *Ci* may also be related to stomatal factors. Besides reducing *gs*, stomatal closure directly reduces CO_2 assimilation, thereby decreasing *Ci* under salt stress. However, photosynthetic rates were maintained or enhanced even under low *gs* and *Ci* (as in A17, A34 and A35 which had 48%, 67% and 32% increases in *A* under salt stress, Table 5), which can be explained by the fact that the substrate supplied the plant demand for water and nutrients favoured by the hydroponic cultivation. Additionally, different *Ci* among plant accessions and cultivars may

Table 9 Mineral nutrient content in roots of melon plants (*Cucumis melo* L.) grown under saline water irrigation

Material	N		P		Ca		Na	
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}
A07	16.60aA	6.33cB	29.33aA	21.80bA	1.24bA	0.35cB	1.50cA	1.50cA
A14	14.90aA	10.23bB	26.10aA	33.86aA	1.34bA	1.27bA	2.83cA	3.00cA
A17	13.16aA	5.00cB	31.70aA	33.60aA	1.62aA	1.23bA	8.26bA	7.13aA
A24	9.26bB	13.40aA	27.70aA	30.73aA	1.36bA	1.33bA	9.96aA	4.83bB
A34	14.00aA	9.03bB	27.70aA	20.96bA	1.75aA	1.34bB	6.33bA	5.63aA
A35	15.93aA	14.30aA	21.10bA	25.53bA	1.86aA	1.81aA	7.63bA	7.16aA
A36	10.36bA	14.30aA	15.96bA	24.40bA	1.94aA	2.02aA	10.16aA	9.10aA
A39	10.36bA	5.00cB	20.86bA	17.96bA	2.01aA	1.62aB	7.23bA	7.30aA
Caribbean Gold	15.66aA	13.80aA	27.60aA	22.63bA	0.53cA	0.62cA	5.76bA	4.90bA
Sancho	13.56aA	16.50aA	23.63bA	27.33aA	0.47cA	0.54cA	9.40aA	6.46aB

	K	Mg	Cl
A07	25.56b	0.41b	23.66d
A14	29.98A	0.58a	72.66b
A17	32.65a	0.12d	26.50d
A24	29.21a	0.18c	26.50d
A34	24.23b	0.33b	77.50b
A35	23.31b	0.36b	11.25d
A36	20.18b	0.43B	117.16a
A39	19.41b	0.36b	48.66c
Caribbean Gold	25.11b	0.23c	52.16c
Sancho	25.48b	0.23c	36.16c

N, K, Ca, Mg and Na are expressed as g kg^{-1} and Cl as mg g^{-1}. Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$). For N, P, Ca and Na there was a significant interaction between materials and the electrical conductivity used in the irrigation. For K, Mg and Cl there was an isolated effect for melon plants

Table 10 Effect of electrical conductivity (EC) of irrigation water on mineral nutrient content in different organs of melon plants (*Cucumis melo* L.)

EC (dS m^{-1})	Root		Stem						Leaf	
	Mg	Cl	N	K	Ca	Mg	Na	Cl	Ca	Cl
4.5	0.37a	58.21a	18.18b	7.64b	2.15a	1.14a	6.83a	67.50a	8.50a	107.20a
0.5	0.27b	40.23b	20.46a	8.92a	1.63b	0.71b	5.28b	52.03b	6.50b	66.58b

N, K, Ca, Mg and Na are expressed as g kg^{-1} and Cl as mg g^{-1}

Means sharing same letter in column are not significantly different according to the Scott-Knott test ($p < 0.05$)

be attributed to genetic variability such as density and size of leaves and stomata, which may change plant behaviour responses to environmental conditions (Arantes et al. 2016). Such variability is attractive in breeding programmes. In situations of severe salt stress, the absence of water makes carbon fixation impossible, as water acts in photosynthetic processes by donating electrons (water photolysis) to perform the photochemical phase and its presence is essential for the generation of ATP and NADPH, important for fixation carbon biochemistry (Lawlor 2002).

WUE increased, decreased or maintained in some plants after imposed salt stress (Table 5). According to Morais et al. (2018), melon plants can benefit from moderate salinity by increasing *WUE*, which is related to decreased *E* and *gs* that decreased water loss as well as increased *Ci*, suggesting that plants subjected to low levels of stress can maximise water use through mechanisms to increase assimilation of CO_2. This feature is desirable in plants that are tolerant to salinity. Increased salinity of the nutrient solution decreases *A*, *gs* and *E*, while it increases *Ci* in melon plants (Fernandes et al. 2010; Morais et al. 2018), which was also found in this study. However, Sousa et al. (2018) observed a decrease in *Ci* in melon plants under saline water irrigation. Such results highlight the genetic diversity among melon plants relating to physiological attributes in response to salt stress.

Table 11 Mineral nutrient content in stems of melon plants (*Cucumis melo* L.) grown under saline water irrigation

Material	P		K	Ca	Mg	Na	Cl
	4.5 dS m^{-1}	0.5 dS m^{-1}					
A07	9.05aA	9.21aA	10.68a	1.59b	1.38a	3.16d	85.50b
A14	10.69aA	7.13aB	11.05a	1.89b	1.63a	3.07d	60.33b
A17	6.26bA	0.56cB	10.65a	1.77b	0.50d	5.57c	35.33c
A24	6.85bA	7.62aA	9.88a	1.85b	0.57d	7.18b	64.00b
A34	2.52cA	2.79bA	7.56b	2.01b	0.99b	3.96d	42.00c
A35	4.31cA	3.99bA	6.13b	2.86a	1.05b	3.93d	44.16c
A36	4.60cA	5.34bA	6.80b	2.35a	0.89c	10.42a	146.33a
A39	4.32cA	4.77bA	6.25b	2.62a	1.13d	9.53a	33.00c
C. Gold	3.71cA	4.22bA	6.76b	1.16c	0.55d	5.53c	53.66b
Sancho	3.76cA	3.73bA	7.05b	0.81c	0.60d	8.14b	33.33c

P, K, Ca, Mg and Na are expressed as g kg^{-1} and Cl as mg g^{-1}

Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$). For P there was a significant interaction between plants and electrical conductivity of irrigation water. For K, Ca, Mg, and Cl there was an isolated effect for melon plants

Table 12 Mineral nutrient content in leaves of melon plants (*Cucumis melo* L.) grown under saline water irrigation

Material	K		Mg		Na		P	Ca	Cl
	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}	4.5 dS m^{-1}	0.5 dS m^{-1}			
A07	39.16bA	7.00cB	1.01cA	0.58bA	4.93aA	3.10aB	8.56	7.96a	116.66a
A14	35.53bA	6.03cB	0.75cA	0.67bA	3.30bA	3.06aA	8.32a	9.16a	91.16a
A17	5.50cA	6.60cA	2.57aA	1.74aB	2.93bA	3.16aA	4.44b	5.52b	88.33a
A24	46.43aA	7.06cB	1.87bA	1.82aA	3.80aA	3.80aA	5.18b	6.31b	69.16b
A34	37.40bA	6.00cB	0.82cB	2.46aA	2.40bA	2.40aA	4.05b	8.02	109.66a
A35	34.40bA	36.50bA	0.82cB	2.32aA	3.83aA	2.30aB	3.13c	8.44a	76.66b
A36	45.13aA	43.53aA	0.92cA	0.69bA	3.56bA	3.66aA	4.13b	9.38a	131.91a
A39	43.80aA	3.76cB	0.73cA	1.14bA	4.43aA	3.56aA	4.88b	10.02a	93.00a
Caribbean Gold	38.43bA	6.73cB	0.55cB	1.92aA	2.76bA	3.00aA	2.69c	5.46b	64.83b
Sancho	31.03bA	4.70cB	0.55cB	2.12aA	3.40bA	4.10aA	4.41b	4.72b	27.50b

P, K, Ca, Mg and Na are expressed as g kg^{-1} and Cl as mg g^{-1}. Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$). For K, Mg, and Na there was a significant interaction between plants and electrical conductivity of irrigation water. For P, Ca, and Cl there was an isolated effect for melon plants

Salinity is one of the significant factors affecting the productivity of plants, as observed. Salinity also affects melon growth components. NL significantly reduced under saline treatment, which was positively correlated with decreased LA ($r = 0.67$). However, we found higher NL (82.7 leaves in A35) than Fernandes et al. (2010) in Hales Best Jumbo melon (59.6 leaves). The authors note that salinity decreases NL in melon plants, and more leaves were found under 0.3 dS m^{-1} electrical conductivity of nutrient solution. This indicates that long periods of salt stress cause damage that directly affects the photosynthetic machinery by a reduction in the photochemical efficiency and suppression of the photosystem II activity (Mehta et al. 2010) and stomatal conductance, causing a metabolic depression in the processes of carbon capture (Saleem et al. 2011).

In this study, salinity did not affect SD in melon plants, unlike that found by Keling et al. (2013) and Dias et al. (2010). However, some growth components increased under saline treatment, such as height and fresh and dry weight, which may be related to a higher K^+/Na^+ ionic ratio in leaves (Table 16). A high correlation between growth, biomass and nutrient accumulation has been reported (Geilfus et al. 2010; Ahmed et al. 2013). In the present study, a positive correlation was found between SD and RDW ($r = 0.67$), RFW and RDW ($r = 0.97$), and FSW and DSW ($r = 0.85$).

However, salinity reduced LA in A35 (Table 6). Such a response was also reported by Medeiros et al. (2012b)

Table 13 Effect of saline water irrigation on the production efficiency index (PEI) and classification for tolerance to salinity according to Fageria (1985)

Material	(PEI)*	Classification
A07	0.73	MT
A14	1.43	T
A17	0.58	MT
A24	0.42	S
A34	0.80	MT
A35	1.83	T
A36	1.19	T
A39	1.54	T
Caribbean Gold	0.58	MT
Sancho	1.32	T

*0 < PEI < 0.5 means susceptible (S); 0.5 < PEI < 1.0 means moderately tolerant (MT); and PEI > 1.0 means tolerant (T)

and Freitas et al. (2014) in melon plants. A reduction in LA under salinity is a mechanism of salt tolerance since reducing the transpiration area avoids water loss. Thus, results showed that the accessions reduced biomass when exposed to salt stress, as revealed by decreased fresh and dry weight, which demonstrated that salinity depressed plant growth. Reduced biomass under salinity may be attributed to decreased osmotic potential in the root zone resulted from excessive salt concentration in the nutrient solution, which causes nutrient imbalance. In addition, salinity impairs plant growth because it induces excessive accumulation of Na^+ and Cl^- in plant tissue and energy deviation from growth

Table 15 Principal component analysis for physiological and growth variables of melons accession and cultivars grown under saline water irrigation

	CP 1	CP 2	CP 3	CP 4
Eigenvalues	5.36	3.56	2.30	1.70
Variance (%)	35.77	23.78	15.38	11.39
Cumulative variance (%)	35.77	59.55	74.94	86.33

to exclude, compartmentalise, or avoid uptake of these ions (Edelstein et al. 2016). Moreover, energy is diverted from growth for the synthesis of compatible solutes to maintain cell turgor under saline condition (Xiong et al. 2018) or enhanced carbohydrate (starch and sugars) accumulation in chloroplasts may also result in attenuated photosynthetic activity (Morais et al. 2019).

The plant ability to maintain high K^+ and Ca^{2+} levels against low Na^+ levels within tissues is another salt-tolerance mechanism. Salt-tolerant genotypes are also able to maintain high K^+/Na^+ ratios in tissues (Zeng et al. 2003), which was also observed in the present study (Xiong et al. 2018). Generally, salinity treatment increased the Na^+ and Cl^- concentration in plant tissue. However, the Na accumulation in roots and stems was higher than in leaves, suggesting that melon plants are able to exclude Na^+ from their growing organs, being an important mechanism for salt tolerance in melon (Sarabi et al. 2017; Xiong et al. 2018). In this sense, higher K^+/Na^+ found in A24, A34, A35, A36, A39 (as also found in Sancho and Caribbean Gold cultivars)

Table 14 Pearson correlation coefficients between physiological and growth variables in melon cultivars and accessions

	E	*gs*	*A*	*Ci*	*WUE*	NL	SD	SH	LA	RFW	SFW	LFW	RDW	SDW
gs	−0.65*													
A	0.93*	−0.61												
Ci	−0.45	0.34	−0.48											
WUE	0.05	−0.47	0.25	−0.03										
NL	0.25	−0.19	0.22	−0.13	−0.13									
SD	0.35	−0.28	0.17	−0.38	−0.10	−0.52								
SH	−0.25	−0.34	−0.34	0.05	0.20	−0.25	0.35							
LA	0.37	−0.27	0.27	0.00	−0.09	0.67*	0.01	0.10						
RFW	0.30	−0.08	0.16	−0.46	−0.39	0.07	0.59	0.33	0.38					
SFW	−0.37	0.32	−0.51	0.02	−0.29	−0.47	0.62	0.58	0.07	0.58				
LFW	−0.09	−0.12	−0.28	0.19	−0.09	0.15	0.39	0.47	0.67*	0.39	0.59			
RDW	0.34	−0.18	0.16	−0.41	−0.40	−0.04	0.67*	0.41	0.28	0.97*	0.57	0.37		
SDW	−0.22	0.09	−0.39	−0.16	−0.32	0.01	0.46	0.67*	0.40	0.76*	0.85*	0.69*	0.72*	
LDW	0.05	−0.15	−0.21	−0.20	−0.41	0.50	0.21	0.44	0.62	0.56	0.41	0.62	0.54	0.77*

E transpiration, *gs* stomatal conductance, *A* net photosynthesis, *Ci* internal concentration of CO_2, *WUE* water use efficiency, *NL* number of leaves, *SD* stem diameter, *SH* shoot height, *LA* leaf area, *RFW* root fresh weight, *SFW* stem fresh weight, *LFW* leaf fresh weight, *RDW* root dry weight, (SDW) stem dry weight, (LDW) leaf dry weight

*significant at $p < 0.05$

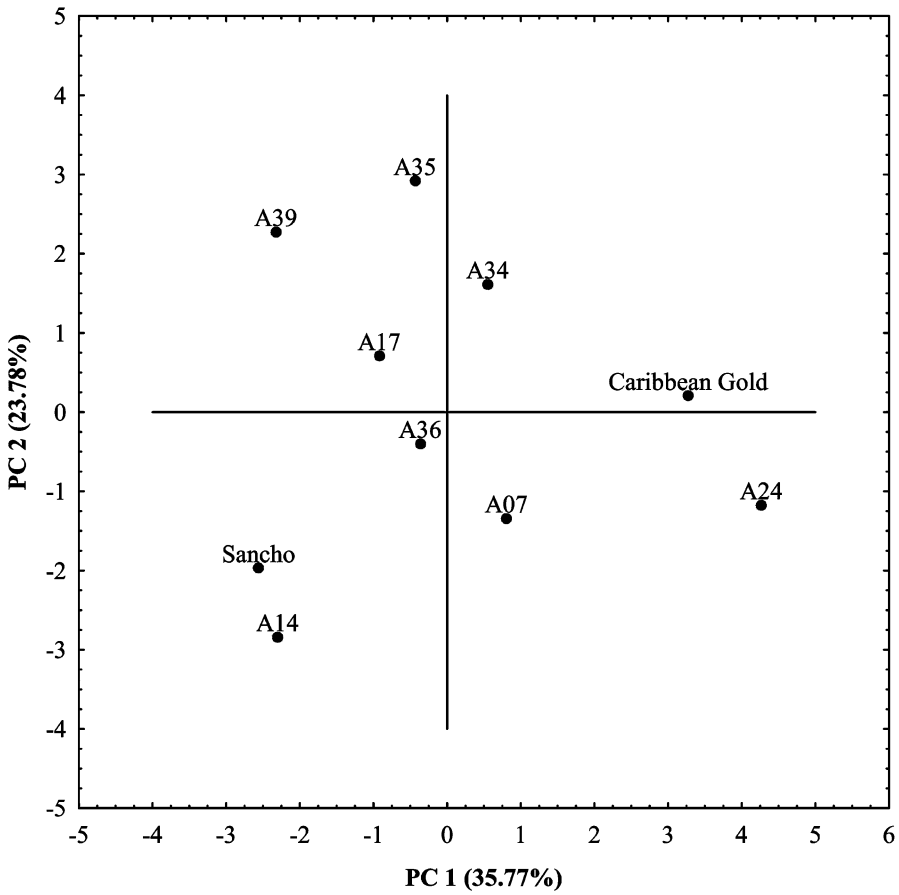

Fig. 1 PCA score plot for the first two major components (jointly explaining 59.55% of variation) with melon materials

indicate that these accessions are more tolerant to salinity than A07, A14 and A17, and might offer genes for salinity tolerance in melon breeding programmes.

In contrast to Na^+, melon plants were not able to restrict Cl^- uptake to shoot, but some accessions excluded more Cl^- than others. Salinity did not affect K^+ accumulation in the roots. However, the Na^+ and Cl^- ions follow distinct accumulation and distribution patterns in plants. Na^+ content differences were observed for the K^+ nutrient in the roots only between the materials, also Na^+ (Sancho and A24) and Cl^- (A14 and A17) increases were observed in the roots. In this study, the effect of K^+ in the roots on nutrient uptake to the melon in relation to salinity is reported in several studies, with a reduction of N, P, K^+ and Ca^{2+} contents and an increase of Na^+ and Cl^- concentrations (Kuşvuran 2012; Rouphael et al. 2012; Yarsi et al. 2017). In the stems, a reduction of K^+ (A14) was observed followed by a greater accumulation of Cl^- (A07) and Na^+ in the materials A35, A36, A39 and Sancho (Table 11). This can be explained as one of the alternatives that salinity-tolerant plants use to reduce the salt load on the cells in their stems by excluding salt ions, or to accumulate in the root system which in turn reduces their translocation to shoots (Edelstein et al. 2016). According to Botía et al. (2005), plants tend to accumulate higher concentrations of Na^+ and Cl^- in the stem preventing these ions from concentrating in the leaves. This behaviour was verified in the present study, in which the highest concentrations of these nutrients were allocated to the roots and stems (Table 8). There are several reports in the literature of the pattern of nutrient absorption in the stem of the melon as a function of the application of salt-water: Na > K > Ca (Kuşvuran 2012); K > N > Ca > P > Mg (Neocleous and Savvas 2015); and Cl > Na > K (Sarabi et al. 2017). Therefore, it is suggested that melon has no effective mechanism to exclude Na^+ after absorption through the Na^+/H^+ antiport in the plasma membrane of root cells nor mechanisms to prevent the transport of these ions (Oliveira et al. 2019).

Most plants increased K^+ concentration in the leaves under saline treatment. Increasing K^+ content in the leaves is important in maintaining cell turgidity, enzyme activity and stomatal activity and consequently, maintaining growth and biomass production under salt stress conditions (Lacerda et al. 2004). Additionally, salt-tolerant plants may produce and activate more K^+ channels to enhance the transport of this nutrient to the leaves (Willadino and Camara 2010). Such results explain why melon plants that accumulated most K^+ into the leaves, although also accumulating Na^+ and Cl^-, such as A36 and A39, grew more and produced more

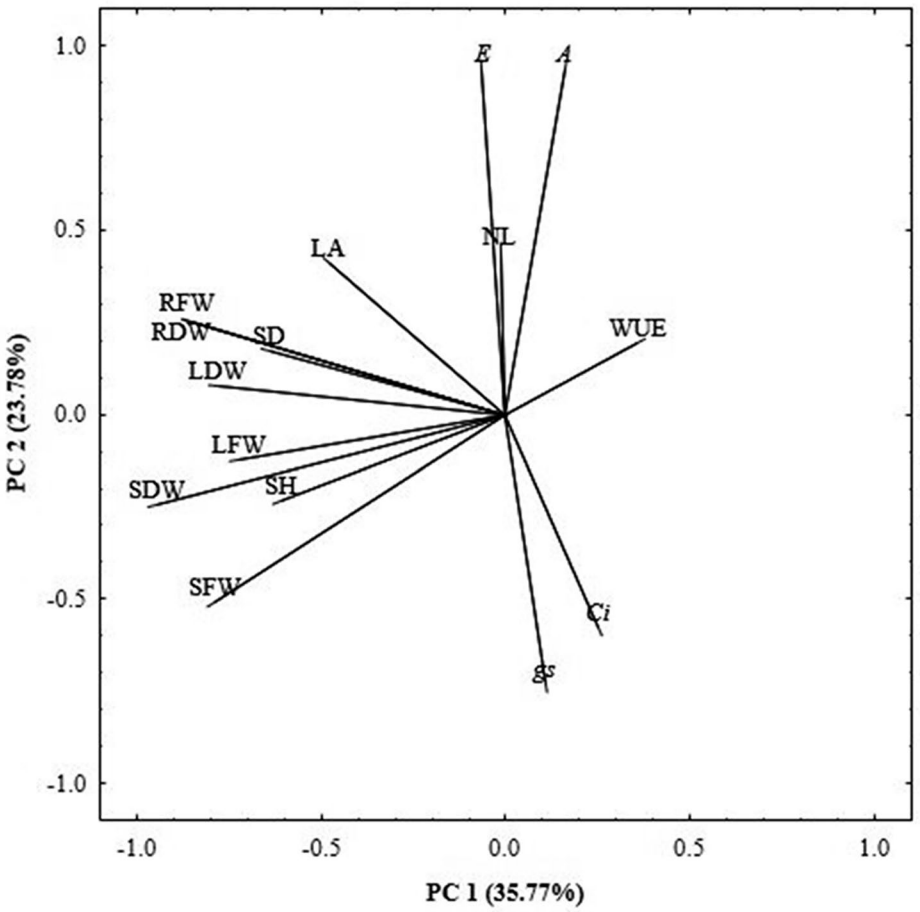

Fig. 2 PCA loading plot for growth and physiological variables of melons accessions and cultivars grown under saline water irrigation. Transpiration (*E*), stomatal conductance (*gs*), net photosynthesis (*A*), internal concentration of CO_2 (*Ci*), *WUE* water use efficiency, *NL* number of leaves, *SD stem diameter*, *SH* height of the aerial part, *LA* leaf area, *RFW fresh weight* of root, *SFW* fresh stem matter, *LFW* fresh leaf matter, *RDW root dry weight*, *SDW* stem dry weight, *LDW* leaf dry weight

biomass, besides being more effective in controlling stomal closure in order to avoid water loss. Variability in nutrient accumulation under salt stress conditions has been reported by many authors (Rouphael et al. 2012; Terceiro Neto et al. 2014; Tedeschi et al. 2016) in many melon cultivars, such as Pele de Sapo, Huanghemi, and Cyrabno. According to Maathuis and Amtmann (1999), the species that keeps K^+ uptake at a minimum level to maintain homeostasis besides to avoid leaf senescence under high salt concentration can be considered tolerant to salt stress (Jaarsma et al. 2013).

Based on growth and physiological attributes, cluster analysis separated A35 from the other melon genotypes, which formed a single group (Fig. 3). Two distinct groups relating to growth and gas exchange analysis were identified: the first cluster comprises the A35 access and the second cluster the materials A07, A39, A14, A34, A36, Caribbean Gold, Sancho and A24. In this analysis, it was verified that the A35 access presents a differential in the morphology and physiology in response to salinity in comparison to the other materials. Sarabi et al. (2017) also verified similarities between Suski-e-Sabz and Ghobadlu materials, which were placed close to F1 Galia as a salinity-tolerant cultivar, indicating similar saline stress behaviour.

Studies have demonstrated that genes, such as allene oxide synthase (AOS) and hydroperoxide lyase (HPL), members of the CYP74 gene family, were found to be associated to inducing stress resistance in a range of plant species, such as tomato, rice, and watermelon (Zhou et al. 2019). Also, plants under abiotic stress conditions increase levels of WRKY transcription factors which increases abscisic acid (ABA) content in leaves alongside gradually decreases leaf water potential and stomatal conductance (Ahammed et al. 2020). Transcription factors (TFs) play key role as mediator of transcriptional reprogramming during biotic and abiotic stresses, leading to adaptation of plants to stressful conditions. Thus, both genes and transcriptions factors can be associated to variability for stress resistance in melon plants. And identifying stress tolerant accessions under imposed salinity stress conditions allows selecting genotypes for breeding programmes. In this sense there is a potential family of genes that has remained absolutely untapped in stress signalling and other aspects of growth and development in plants. Ganie, Ahammed and Wani (2020) plausibly suggested in rice a possible connection between VOZ genes and abiotic stress. Other findings in the literature may be of practical importance for the management of crops subjected

Table 16 K/Na ratio of roots, stems and leaves of melon (*Cucumis melo*) as a function of irrigation with saline water

SV	DF	Mean square		
		Root	Stem	Leaf
Block	2	0.29 ^{ns}	0.45 ^{ns}	0.10 ^{ns}
Materials (M)	9	161.80**	7.31**	67.89**
Salinity (S)	1	2.60 ^{ns}	7.62**	576.41**
M x S	9	9.33 ^{ns}	0.53*	56.25**
Error	38	7.91	0.23	4.21
Mean		5.93	1.80	7.46
CV%		47.42	27.03	27.51

Plant	K/Na									
	Root		Stem				Leaf			
			4.5 dS m^{-1}		0.5 dS m^{-1}		4.5 dS m^{-1}		0.5 dS m^{-1}	
A07	19.28	a	2.68	aB	4.83	aA	8.46	bA	2.64	cB
A14	10.23	b	3.01	aB	4.25	aA	10.98	bA	1.99	cB
A17	4.38	c	1.78	bA	2.09	bA	1.88	cA	2.13	cA
A24	4.90	c	1.22	cA	1.63	bA	12.28	aA	1.87	cB
A34	4.41	c	1.75	bA	2.25	bA	16.05	aA	2.57	cB
A35	3.25	c	1.22	cB	2.24	bA	10.08	bB	15.93	aA
A36	2.16	c	0.54	cA	0.84	cA	12.68	aA	12.03	bA
A39	2.67	c	0.49	cA	0.88	cA	9.92	bA	1.05	cB
Caribbean Gold	4.65	c	0.99	cA	1.50	cA	13.97	aA	2.24	cB
Sancho	3.36	c	0.75	cA	1.04	cA	9.30	bA	1.19	cB

SV Source of variation, *DF* degrees of freedom, *CV* coefficient of variation

**, *Significant at $p < 0.01$ and $p < 0.05$, respectively, according to the F test; ns: not significant. For K/Na in roots there was isolated effect for melon plants; for K/Na in stem and leaves was a significant interaction between plants and electrical conductivity of irrigation water. Means sharing an uppercase letter in line or lowercase in column for each variable are not significantly different according to the Scott-Knott test ($p < 0.05$)

to abiotic stresses for sustainable production. Zhang et al. (2019) suggest that exogenous Si application alleviat oxidative stress and increased acquisition of most essential nutrients.

In this study PCA helped to understand the differences and similarities among melon in response to salt stress. PC1 explained 35.77% of total variance and separated melon plants mainly by growth variables (SD, SH, LFW, LDW, SFW, SDW, RFW, RDW), while PC2 explained 23.78% and separated plants by gas exchange (*A*, *E*, *Ci* and *gs*) (Fig. 2). The principal components successfully separated the studied materials, separating the most salt-tolerant material (Sancho) from the most susceptible (Caribbean Gold) (Fig. 1). The distance between Sancho and Caribbean Gold indicates the response divergence between them. This may aid identification of the tolerant and susceptible accessions to saline water among the studied accessions from the germplasm bank. The set of responses was enough to ensure the better performance of Sancho under stress. The different melons analysed present alternative pathways and mechanisms that, in turn, may produce different phenotypical responses. Considering these results, tolerable salinity levels and suitable cultivation time must be considered. The tolerance of different accessions to salt stress is quite different, indicating that extensive comparisons will be required to identify melon suitable for selective breeding.

When plants are subjected to salt stress, some adaptative responses are observed. In the present study, the different melon accessions showed different morphological, nutritional and physiological changes, with huge variability among them for the studied variables. A35 showed mechanisms that indicated it as the most salt-tolerant among the studied accessions, as revealed by its higher number of leaves and biomass and also lower Na^+ and Cl^- concentration in root, stem, and leaves, thus being indicated as a parent to obtain more tolerant plants against salinity. Some other accessions, such as A24 and A36, in contrast, did not reveal adaptation mechanisms

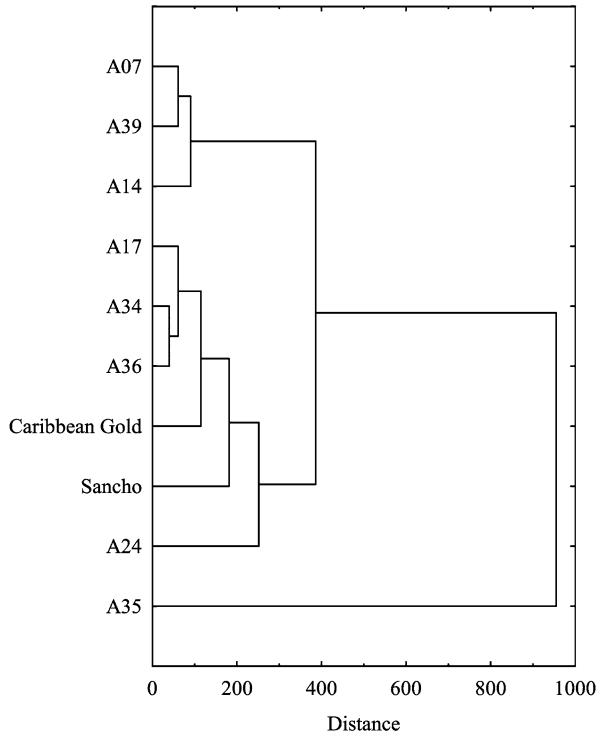

Fig. 3 Cluster analysis by UPGMA (Unweighted pair-group average) and Euclidean distance for melon accessions and cultivars grown under saline water irrigation

to salt stress, showing lower biomass and higher Na^+ and Cl^- concentration in tissues.

Conclusions

NaCl induced different physiological responses, causing growth inhibition with relevant variations among accessions;

The A24 accession was classified as susceptible to salinity with low production efficiency;

The A35 accession stood out with high performance in gas exchange and growth analysis, being a promising candidate for successful adaptation to saline environments.

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Author Contributions FHAS participated in the data collection, designed the experiments, data analysis and wrote the manuscript. NDS, MBM and MTAN participated in the interpretation, reviewed the article and provided editorial advice. MFM and GHSN performed the statistical analyses. PLDM guided every step of the work and participated in the drafting and review of the project and of the article.

Compliance with Ethical Standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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