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Internal Fruit Quality Is Maintained in Eggplant under Mild Long-Term Salt Treatment

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Abstract: Modern *Solanum melongena* varieties have been developed to improve the content of phenolics, sugars, and nutritionally relevant minerals in fruit. However, fruit composition might be altered due to abiotic stresses like salinity. Physiological and fruit quality traits were evaluated in four eggplant landraces under usual irrigation and moderately salty irrigation conditions (80 mM NaCl). Growing parameters measured included root length, leaf surface, and fresh weight, while fruit composition traits included sugars, phenolics, and mineral content determinations. Few differences were observed for agronomic traits, probably due to the mild tolerance of eggplant to salinity. Some varieties showed signs of salt tolerance like an increase in primary root length to overcome salt stress. Glucose was the metabolite more affected by the salt treatment in the fruit, while phenolic compounds and other metabolites studied were not altered. Significant differences were observed in the main minerals Na, K, Ca, P, and Mg, both between genotypes and treatments. Although salinity produced changes in some physiological and developmental traits, the composition of the fruit was not significantly modified for the accessions tested. Mineral, sugar, and phenolic contents were not particularly altered in unripe fruits, indicating tolerance of eggplant varieties to salinity in terms of fruit quality.

Keywords: chlorogenic acid; minerals; phenolic compounds; salt stress; *Solanum melongena*; sugars

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1. Introduction

Eggplant, or brinjal (*Solanum melongena* L.), is one of the main vegetable crops worldwide, with a total production of over 50×10^6 t [1]. Eggplant fruits are known for their high phenolic content, mostly anthocyanins, in the peel and chlorogenic acid in the flesh [2]. In addition, eggplant is a good source of diverse minerals, whereas it has a moderate sugar content [3]. Eggplant has a wide natural variation between genotypes for its nutraceutical composition, which could be of interest to new quality breeding programs [4–6].

In many agricultural areas of the world, deficient use of irrigation water, application of fertilizers, poor drainage systems, and accumulation of Na^+ and K^+ ions in soils may cause severe problems like salinity, which affects the production of many economically important crops [1,7]. Moreover, soil salinization is one of the consequences of climate change due to the alteration in patterns of precipitation and the dramatic reduction in water availability and water use efficiency because of CO_2 accumulation [8].

Under saline conditions, plant growth is impaired, and many physiological parameters are affected, such as photosynthesis, nutrient acquisition, and transportation. Also, normal cellular and enzymatic activity can be altered due to the reduction in water availability, ion toxicity, and K^+ deficiency, which induces osmotic imbalances in the cells and oxidative

stress in plants [9,10]. If the stress is prolonged during the season, even mild salinity can remarkably alter yield and fruit quality [11].

As salt affects the metabolic profile of the plant, it also may affect fruit composition. Interestingly, this effect is not always negative for fruit quality. In tomatoes, for instance, an improvement in the fruit quality when plants are subjected to moderately saline irrigation, particularly in sugar and acid contents, as a result of osmotic adjustments has been reported [12,13]. In response to salt stress, tomato plants decrease plant growth and yield and start accumulating specific metabolites, some of them in the fruit, through reducing water content, which is commonly known as the "concentration effect" [13–15].

Although being described as a glycophyte, eggplant has been demonstrated to have a higher tolerance to salt than other Solanaceae species [16–18]. Moreover, eggplant rootstocks are commonly used to alleviate salinity stress in tomatoes [19]. In a saline environment, eggplant changes the absorption, transport, and accumulation of ions [17]. This competition causes a loss in yield and plant growth and can cause a deviation compared to normal mineral accumulation in fruit. However, information on how salinity affects fruit quality in eggplant is scarce or almost nil.

The aim of this work is to identify the differences in fruit composition due to eight weeks of salt irrigation in four cultivated *Solanum melongena* L. genotypes by analyzing plant growth parameters, total phenolic compounds, sugars, and mineral composition of the fruit. Hence, understanding the importance of eggplant in future meal plans when cultivated in changing environments.

2. Materials and Methods

2.1. Plant Material and Seed Germination

Four *Solanum melongena* commercial cultivars were used for this experiment. MEL1 originated in the Ivory Coast, and MEL5 originated in Sri Lanka, as referred to in Plazas et al. [20]. ALM and LdG are two Spanish landraces referred to in Vilanova et al. [21]. To improve germination, seeds were sown following the protocol described by Ranil et al. [22]. Seeds were immersed in distilled water for 24 h and then in gibberellic acid 500 ppm for 24 h. Afterward, seeds were placed in Petri dishes (90 mm in diameter) over sterile cotton and filter paper watered with KNO_3 1000 ppm. A hot shock of 37 °C was applied for 24 h after a cold treatment at 4 °C for 7 days. Petri dishes were placed in a germination and growing chamber at 25 °C, 78% humidity, and a 16/8 photoperiod.

2.2. Plant Growth and Salt Treatment

Ten plants per genotype at the 4-leaf stage were transplanted into the greenhouse to 33 × 29 cm pots (15 L capacity) with coconut fiber. Fertilizer CoteN Mix (Haifa Negev Technologies Ltd., Haifa, Israel) with NPK = 20-5-10 and control release was added to each pot every 3 to 4 weeks. They were grown until the pre-flowering stage, when the salt treatment started. Plants were watered through automated irrigation of 1.65 L daily with 4 L h^{-1} emitters and 3 irrigation times of 5 min. Two treatments were tested: 5 plants were watered with a non-saline (control) solution, and the other 5 with a solution containing 80 mM of added NaCl. Once a week, plants were irrigated with the control solution to simulate eventual natural rain on the crop. In this way, we could achieve the electrical conductivity of high–moderate saline areas in eastern Spain, which ranges from 4 to 6 dS/m [23,24].

After 8 weeks of salt treatment, the following parameters were measured: primary root length (RL, cm) determined with the clean root extended from the neck to the apex, leaf surface (LS, cm^2), determined with Digimizer image analysis software version 6.4.0 (MedCalc Software Ltd., Ostend, Belgium), root fresh weight (Rfw, g), and leaf fresh weight (Lfw, g). Part of the material was dried for three days at 65 °C and weighted to calculate water content (WC, %) using the following formula:

$$WC\ (\%) = [(fw - dw)/fw] \times 100$$

2.3. Substrate Electrical Conductivity

The electrical conductivity ($EC_{1:5}$) of the substrate was determined at the end of the experiment with 5 g of the dried coconut fiber from each pot diluted with 30 mL of MilliQ water. The solution was shaken for 2 h at 600 rpm and filtered for big particles. $EC_{1:5}$ (dS m^{-1}) was measured with a Crison conductivity meter 522 (Crison Instruments SA, Barcelona, Spain).

2.4. Fruit Weight

Measurements of fruit weight (FW) (g) were taken from the fruit production for all genotypes. Fruit collection started after 1 week of salt treatment. The quantity of fruits per genotype was variable, with a minimum of five fruits under salinity treatment and a maximum of ten fruits. After weighting, fruit flesh was lyophilized (VirTis Genesis, SP Scientific, Warminster, PA, USA) for further measurements. Fruit yield was not recorded, as the pollination in the greenhouse was poor, and, therefore, the fruit setting was not representative of a commercial eggplant crop.

2.5. Mineral Content Quantification

Mineral content was extracted from 2 g samples of dry root, leaf material, and lyophilized fruit, as described by Raigon et al. [3], and quantified with an inductively coupled plasma spectrometer ICP-EOS 710 (Agilent Technologies, Santa Clara, CA, USA). Ion concentrations were expressed in mg 100 g^{-1} dw.

2.6. Phenolic Compounds Quantification in Fruit

Total phenolic compounds (TPCs) were extracted from 125 mg of lyophilized fruit weight, following the Folin–Ciocaltieu method, and quantified based on a colorimetric reaction measuring absorbance at 750 nm [25], referring to chlorogenic acid as control. TPCs were expressed in mg TPC g^{-1} dw.

2.7. Chlorogenic Acid and Sugar Contents in Fruit

For the sugar determinations, 0.100 g of lyophilized material was diluted in 1.5 mL of ultrapure water. The samples were extracted with a vortex agitator set at maximum rpm rotational speed for 1 min and centrifugated for 5 min at 12,000 rpm. The supernatant was filtered through 0.22 µm PVDF syringe filters and analyzed in an Agilent 1220-Infinity HPLC System (Agilent Technologies, Santa Clara, CA, USA). The compound separation was performed with a Luna® Omega SUGAR LC column (150 mm × 4.6 mm i.d., 3 µm particle size) (Phenomenex, Torrance, CA, USA) and a guard column (SUGAR, 4 mm × 3.0 mm i.d.). Quantifications were based on calibration curves prepared for glucose (GLU), fructose (FRU), and sucrose (SUC) by the external standard method from 0.3 g L^{-1} to 20 g L^{-1}, and quantities were expressed in mg g^{-1} dw [26].

Chlorogenic acids were extracted and quantified according to Plazas et al. [27]. First, 0.05 g of lyophilized samples were homogenized with 1.5 mL of methanol/water (80:20, *v*/*v*) plus 0.1% (*w*/*v*) of 2,3-tert-butyl-4-hydroxyanisole (BHT). The total extract was vortexed vigorously, sonicated for 1 h at room temperature, and then centrifuged at 10,000 rpm for 5 min. The supernatant was filtered through 0.22 µm PTFE syringe filters and analyzed by HPLC-UV at 325 nm. The analysis was performed on a Brisa C18 column (3 µm; 150 × 4.6 mm) (Teknokroma Analítica S.A., Barcelona, Spain). Quantification was based on external calibration obtained by serial dilutions of commercial standard chlorogenic acid covering the concentration ranges from 20 to 500 mg L^{-1}, and quantities were expressed in mg g^{-1} dw.

2.8. Data Analysis

Data statistical analysis was made with Statgraphics Centurion XVII.I (Statpoint Technologies, Warrenton, VA, USA). A factorial analysis was performed for all the parameters quantified considering as factors genotype, treatment, and their interaction. Statistical dif-

ferences between treatments and genotypes were evaluated with a Student–Newman–Keuls test. Correlations between ion accumulation in different organs were also calculated.

3. Results

3.1. Substrate Electrical Conductivity

Electrical conductivity was measured after 8 weeks of salt treatment ($EC_{1:5}$). The values obtained in both treated and non-treated plant pots were similar for all genotypes. However, ALM showed a slightly higher salt presence in control plant pots compared to MEL1, probably due to the different water requirements between them (Table 1).

Table 1. Electrical conductivity ($EC_{1:5}$ mean ± SD; n = 5) in the pots after 8 weeks of treatment of *Solanum melongena* accessions under control and saline irrigation (80 mM) treatments. Different letters indicate statistically significant differences between genotypes ($p < 0.05$) within each treatment. The asterisk indicates statistically significant differences between treatments ($p < 0.05$) on the corresponding genotype, according to the Student–Newman–Keuls multiple range test.

	Genotype	Control	Salt Treatment
$EC_{1:5}$	MEL1	1.86 ± 1.1^{A}	$4.36 \pm 0.4^{A,*}$
	MEL5	1.2 ± 0.1^{AB}	$5.61 \pm 0.8^{A,*}$
	LdG	1.78 ± 0.2^{AB}	$5.3 \pm 0.3^{A,*}$
	ALM	2.32 ± 0.2^{B}	4.02 ± 2.1^{A}

3.2. Plant Growth Parameters

The water content of the genotypes was not greatly affected by the salt treatment (Figure 1). Therefore, the water content of the roots remained around 75%, no matter the genotype or treatment (Figure 1a), whereas the leaf water content was around 85% except for MEL1 and MEL5, which showed a reduced leaf water content under stress (Figure 1b).

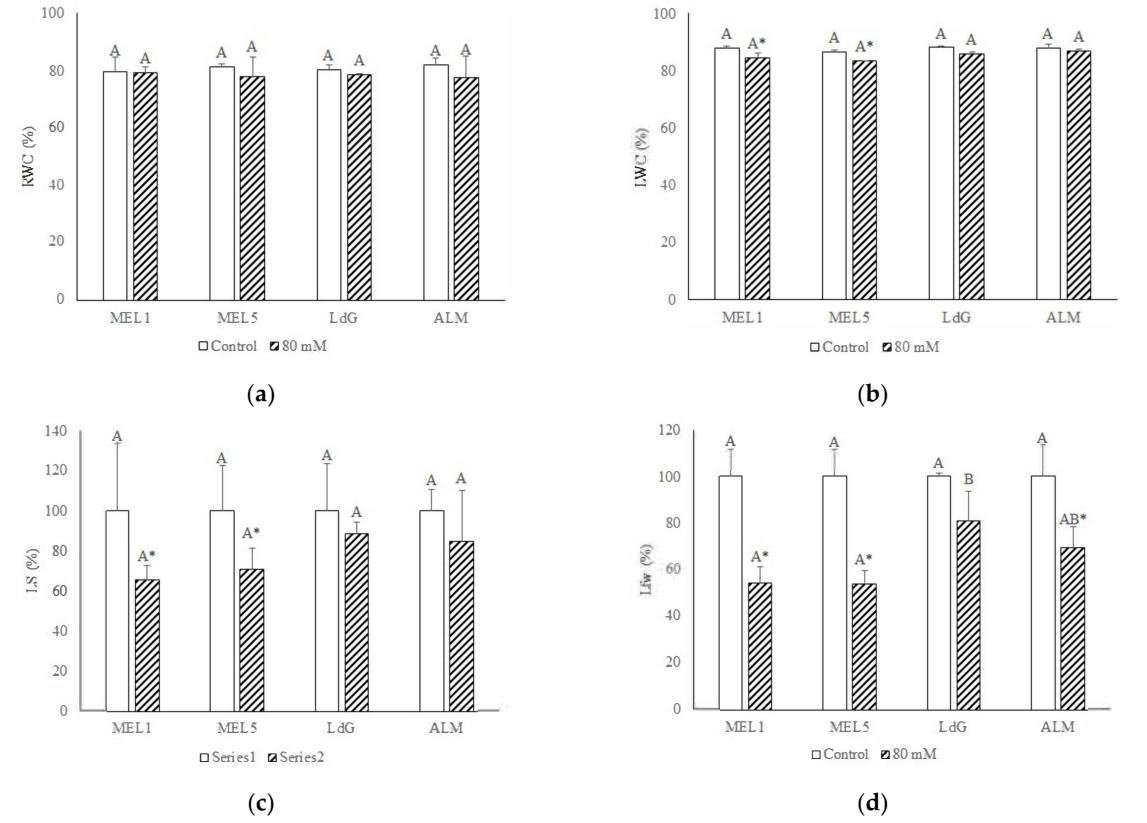

Figure 1. *Cont.*

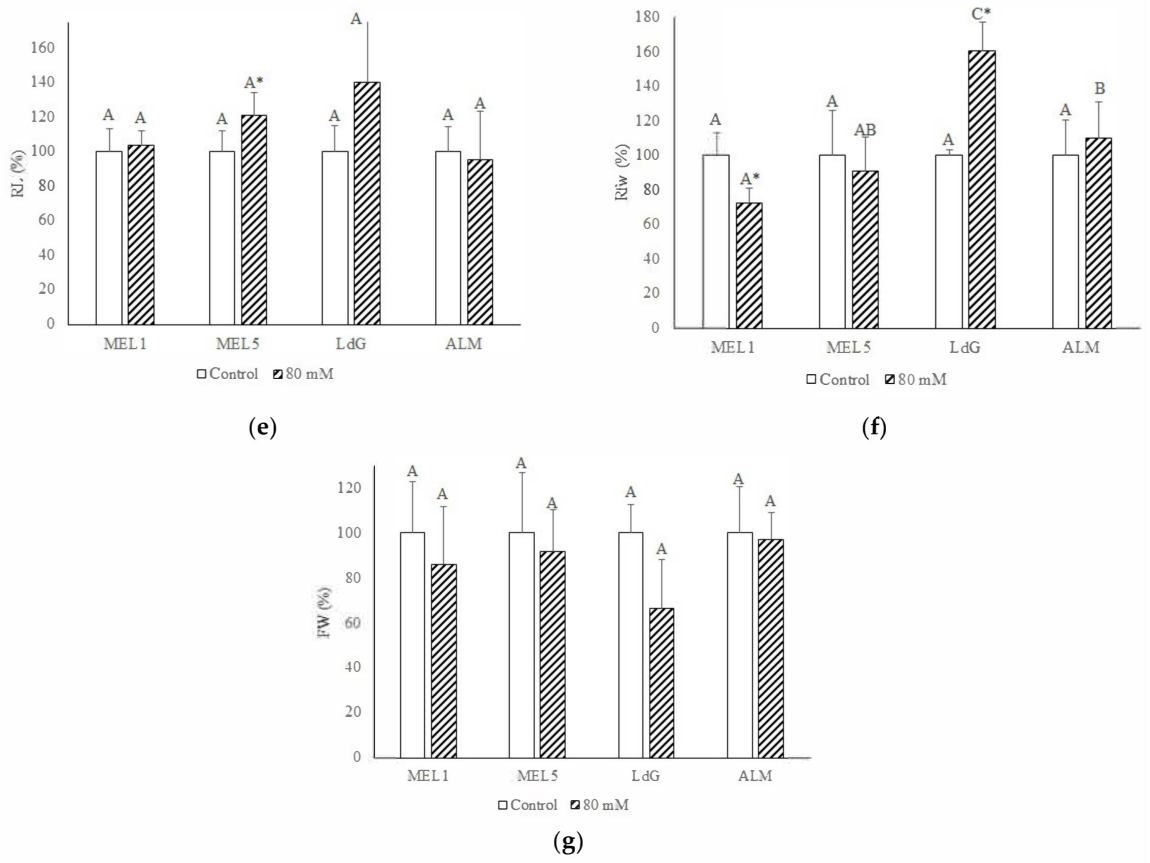

Figure 1. (**a**) Root water content (RWC), (**b**) leaf water content (LWC), (**c**) leaf surface (LS), (**d**) leaf fresh weight (Lfw), (**e**) root length (RL), (**f**) root fresh weight (Rfw), and (**g**) fruit weight (FW) (mean ± SD; $n = 5$) for *Solanum melongena* accessions under control and saline irrigation (80 mM) treatments. Different letters indicate statistically significant differences between genotypes ($p < 0.05$) within each treatment. The asterisk indicates statistically significant differences between treatments ($p < 0.05$) in the corresponding genotype, according to the Student–Newman–Keuls multiple range test.

As different varieties, the accessions showed differences in their aerial part size in control conditions and were affected by salt stress in different ways. Thus, MEL1 and MEL5 significantly reduced their leaf surface (LS) (Figure 1c) and their leaf fresh weight (Lfw) (Figure 1d). This was not the case for LdG, which was not affected by the salt treatment in the aerial traits. Finally, ALM was affected in Lfw but not in LS. However, LdG and ALM were less affected than MEL cultivars.

Both control and stress conditions did not affect the weight of roots. The only exception was MEL5, which increased the root length (RL) under salt treatment, and MEL1 and LdG, which showed opposite responses to salt (Figure 1e). The first one decreased considerably Rfw under saline conditions, while the second one increased Rfw (Figure 1f).

As expected, fruit weight (FW) differed greatly among accessions under control conditions, and the salt treatment only produced a slight decrease in LdG fruit weight (Figure 1g).

3.3. Mineral Composition in Leaves, Roots and Fruits

The tested genotypes showed significant differences in their root mineral composition under control conditions for P, Mg, B, and Mn and in their leaf mineral composition for Na, Ca, P, Mg, B, and Mn. Therefore, K, Fe, and Zn showed similar basal values among genotypes (Table 2). The treatment with saline irrigation modified those mineral contents in a genotype-dependent manner.

Table 2. Mineral composition (mg 100 g^{-1} dw) in root, leaf, and fruit (mean ± SD; n = 5) of *Solanum melongena* accessions under control and saline irrigation (80 mM) treatments. Different letters indicate statistically significant differences between genotypes ($p < 0.05$) within each treatment. The asterisk indicates statistically significant differences between treatments ($p < 0.05$) on the corresponding genotype, according to the Student–Newman–Keuls multiple range test.

		NaCl Treatment (mM)						Fold-Change Salt vs. Control		
		Root		Leaf		Fruit		Root	Leaf	Fruit
		0	80	0	80	0	80			
Na	MEL1	4.22 ± 1.6 ^{A}	10.29 ± 0.7 ^{A}	0.17 ± 0.1 ^{AB}	2.88 ± 0.7 ^{B}	0.34 ± 0.2 ^{A}	4.45 ± 0.6 ^{A}	2.44 *	17.44 *	13.19 *
	MEL5	3.25 ± 0.8 ^{A}	12.65 ± 1.4 ^{A}	0.13 ± 0.1 ^{AB}	1.09 ± 0.4 ^{A}	0.45 ± 0.2 ^{A}	2.36 ± 1.1 ^{A}	3.89 *	8.66 *	5.29 *
	LdG	4.12 ± 1.7 ^{A}	13.47 ± 0.5 ^{A}	0.09 ± 0 ^{A}	1.52 ± 0.1 ^{AB}	0.76 ± 0.4 ^{A}	4.02 ± 0.3 ^{A}	3.27 *	17.64 *	5.31 *
	ALM	5.7 ± 1.2 ^{A}	12.25 ± 2.2 ^{A}	0.22 ± 0.1 ^{AB}	0.9 ± 0.6 ^{A}	0.38 ± 0.2 ^{A}	2.54 ± 0.9 ^{A}	2.15 *	4.13 *	6.69 *
K	MEL1	7.79 ± 0.8 ^{A}	7.07 ± 2.1 ^{A}	11.12 ± 0.6 ^{A}	10.26 ± 0.5 ^{AB}	9.66 ± 0.3 ^{A}	9.01 ± 0.4 ^{A}	0.91	0.92 *	0.93 *
	MEL5	7.09 ± 1.2 ^{A}	6.37 ± 0.7 ^{A}	10.54 ± 0.2 ^{A}	9.82 ± 0.4 ^{A}	9.52 ± 0.4 ^{A}	9.71 ± 0.5 ^{A}	0.90	0.93 *	1.02
	LdG	7.13 ± 0.5 ^{A}	5.24 ± 1.2 ^{A}	10.46 ± 0.3 ^{A}	10.75 ± 0.7 ^{B}	9.82 ± 0.1 ^{A}	9.13 ± 0.5 ^{A}	0.74	1.03	0.93
	ALM	7.69 ± 0.7 ^{A}	6.75 ± 1.9 ^{A}	10.37 ± 0.3 ^{A}	10.49 ± 0.5 ^{AB}	9.41 ± 0.2 ^{A}	8.75 ± 0.4 ^{A}	0.88	1.01	0.93 *
Ca	MEL1	11.52 ± 1.1 ^{A}	8.8 ± 1.5 ^{A}	20.55 ± 2.2 ^{AB}	18.78 ± 2.6 ^{AB}	3.25 ± 0.9 ^{B}	2.96 ± 0.8 ^{A}	0.76 *	0.91	0.91
	MEL5	13.27 ± 1.2 ^{A}	13.17 ± 2.9 ^{B}	21.58 ± 2.8 ^{AB}	21.7 ± 2.7 ^{BC}	2.63 ± 0.2 ^{AB}	2.4 ± 0.3 ^{A}	0 99	1.01	0.91
	LdG	13.3 ± 1.4 ^{A}	12.68 ± 3.6 ^{B}	25.76 ± 3.9 ^{BC}	22.86 ± 2.8 ^{BC}	2.85 ± 0.6 ^{AB}	3.23 ± 0.4 ^{A}	0.95	0.89	1.13
	ALM	12.44 ± 0.9 ^{A}	14.05 ± 1.6 ^{B}	28.33 ± 2.5 ^{C}	25.25 ± 1.5 ^{C}	2.2 ± 0.4 ^{AB}	2.09 ± 0.2 ^{A}	1.13	0.89	0.95
P	MEL1	3.91 ± 1 ^{B}	2.42 ± 0.3 ^{A}	7.6 ± 0.3 ^{B}	5.87 ± 1.5 ^{A}	4.11 ± 0.4 ^{A}	4.49 ± 0.3 ^{A}	0.62 *	0.77 *	1.09
	MEL5	2.51 ± 0.4 ^{A}	2.39 ± 0.4 ^{A}	5.8 ± 0.2 ^{A}	5.72 ± 0.2 ^{A}	4.78 ± 0.3 ^{AB}	4.88 ± 0.4 ^{AB}	0.95	0.99	1.02
	LdG	2.8 ± 0.1 ^{A}	2.51 ± 0.2 ^{A}	6.76 ± 0 ^{B}	7.39 ± 0.8 ^{A}	4.84 ± 0.2 ^{AB}	5.12 ± 0.6 ^{AB}	0.89	1.09	1.06
	ALM	2.63 ± 0.4 ^{A}	2.56 ± 0.5 ^{A}	6.73 ± 0.5 ^{B}	6.69 ± 0.8 ^{A}	5.36 ± 0.4 ^{B}	5.5 ± 0.2 ^{B}	0.97	0.99	1.03
Mg	MEL1	4.25 ± 0.3 ^{AB}	3.41 ± 0.5 ^{A}	5.54 ± 0.3 ^{A}	5.17 ± 0.4 ^{A}	2.94 ± 0.2 ^{A}	2.79 ± 0.3 ^{AB}	0.80 *	0.93	0.95
	MEL5	4.09 ± 0.4 ^{AB}	3.54 ± 0.4 ^{A}	6.22 ± 0.5 ^{A}	6.43 ± 0.4 ^{BC}	2.75 ± 0.1 ^{A}	2.94 ± 0.2 ^{AB}	0.87 *	1.03	1.07
	LdG	4.63 ± 0.2 ^{B}	3.93 ± 0.4 ^{A}	6.21 ± 0.2 ^{A}	5.76 ± 0.4 ^{AB}	3.11 ± 0.2 ^{A}	3.22 ± 0.2 ^{B}	0.85	0.93	1.03
	ALM	4.11 ± 0.3 ^{AB}	3.79 ± 0.7 ^{A}	7.5 ± 0.4 ^{B}	7.01 ± 0.4 ^{C}	2.72 ± 0.2 ^{A}	2.57 ± 0.1 ^{AB}	0.92	0.93	0.95
Fe	MEL1	0.71 ± 0.1 ^{A}	0.67 ± 0.1 ^{A}	0.09 ± 0 ^{A}	0.08 ± 0 ^{A}	0.03 ± 0 ^{B}	0.04 ± 0 ^{A}	0.94 *	0.85	1.23
	MEL5	0.98 ± 0.3 ^{A}	0.91 ± 0.2 ^{A}	0.09 ± 0 ^{A}	0.08 ± 0 ^{A}	0.03 ± 0 ^{AB}	0.02 ± 0 ^{A}	0.93	0.82 *	0.96
	LdG	0.73 ± 0.1 ^{A}	0.74 ± 0.4 ^{A}	0.09 ± 0 ^{A}	0.09 ± 0 ^{B}	0.03 ± 0 ^{AB}	0.03 ± 0 ^{A}	1.01	0.94	1.12
	ALM	0.53 ± 0.3 ^{A}	0.72 ± 0.3 ^{A}	0.08 ± 0 ^{A}	0.1 ± 0 ^{C}	0.02 ± 0 ^{A}	0.02 ± 0 ^{A}	1.35	1.39 *	1.00
B	MEL1	0.01 ± 0 ^{A}	0.012 ± 0 ^{A}	0.05 ± 0 ^{AB}	0.05 ± 0 ^{B}	0.02 ± 0 ^{B}	0.02 ± 0 ^{A}	0.79 *	1.00	0.76
	MEL5	0.011 ± 0 ^{A}	0.011 ± 0 ^{A}	0.06 ± 0 ^{B}	0.06 ± 0 ^{C}	0.02 ± 0 ^{AB}	0.02 ± 0 ^{A}	0.92	1.03	1.06
	LdG	0.011 ± 0 ^{A}	0.01 ± 0 ^{A}	0.05 ± 0 ^{AB}	0.04 ± 0 ^{A}	0.02 ± 0 ^{AB}	0.02 ± 0 ^{A}	0.91	0.73 *	1.00
	ALM	0.014 ± 0 ^{B}	0.011 ± 0 ^{A}	0.06 ± 0 ^{B}	0.05 ± 0 ^{B}	0.02 ± 0 ^{AB}	0.01 ± 0 ^{A}	1.20 *	0.84 *	0.88
Mn	MEL1	0.06 ± 0 ^{AB}	0.05 ± 0 ^{A}	0.07 ± 0 ^{A}	0.06 ± 0 ^{A}	0.02 ± 0 ^{B}	0.02 ± 0 ^{A}	0.88	0.84	0.91
	MEL5	0.07 ± 0 ^{B}	0.07 ± 0 ^{A}	0.11 ± 0 ^{B}	0.07 ± 0 ^{A}	0.02 ± 0 ^{AB}	0.02 ± 0 ^{A}	1.01	0.65 *	0.89 *
	LdG	0.05 ± 0 ^{AB}	0.05 ± 0 ^{A}	0.12 ± 0 ^{BC}	0.08 ± 0 ^{A}	0.02 ± 0 ^{B}	0.02 ± 0 ^{A}	1.11	0.64 *	0.96
	ALM	0.03 ± 0 ^{A}	0.05 ± 0 ^{A}	0.14 ± 0 ^{C}	0.11 ± 0 ^{B}	0.02 ± 0 ^{AB}	0.02 ± 0 ^{A}	1.50 *	0.77 *	0.95
Zn	MEL1	0.02 ± 0 ^{A}	0.01 ± 0 ^{A}	0.09 ± 0.1 ^{A}	0.03 ± 0 ^{A}	0.04 ± 0 ^{A}	0.05 ± 0 ^{B}	0.64 *	0.35 *	1.18
	MEL5	0.02 ± 0 ^{A}	0.01 ± 0 ^{A}	0.08 ± 0 ^{A}	0.11 ± 0.1 ^{A}	0.04 ± 0 ^{A}	0.03 ± 0 ^{AB}	0.82	1.36	0.76
	LdG	0.01 ± 0 ^{A}	0.02 ± 0 ^{A}	0.12 ± 0.1 ^{A}	0.08 ± 0 ^{A}	0.03 ± 0 ^{A}	0.03 ± 0 ^{A}	1.42	0.64	0.76
	ALM	0.02 ± 0 ^{A}	0.04 ± 0 ^{A}	0.05 ± 0 ^{A}	0.11 ± 0 ^{A}	0.03 ± 0 ^{A}	0.03 ± 0 ^{AB}	1.86	2.15*	1.28

Na concentration increased considerably under salt treatment. Thus, all the genotypes doubled (MEL 1 and ALM) or even tripled (MEL5 and LdG) their Na content in the roots under the salt treatment (Table 2). In comparison, the response to the salt treatment observed in the leaves was still more diverse. Thus, MEL1 and LdG accumulated 17-fold Na content in the leaves of salt-treated plants in comparison to the control, whereas MEL5 and ALM accumulated 8.6- and 4.1-fold Na, respectively. By contrast, the levels of K present in roots and leaves were barely affected by the salt treatment, except for 0.9-fold in the leaves of MEL1 and MEL5 under salt stress (Table 2).

Regarding the other minerals assessed, the effects of saline stress were scarce, apart from some exceptions (Table 2). For example, the most affected genotype by the salt treatment at the mineral level was MEL1, which showed lower levels of Ca, P, Mg, Fe, B, and Zn root concentrations and P in the leaves in comparison to control conditions. ALM, on the contrary, only decreased leaf mineral composition for Ca and B and showed an increase in Fe and Zn under this condition. ALM also increased its root concentration of Mn under salt treatment. MEL5 was affected at Mg root concentrations and Fe leaf concentrations. Finally, LdG was the less affected genotype, with changes only at leaf B concentration (Table 2).

Similar to the roots and leaves, the basal levels of Na and K concentrations in the fruits were similar among genotypes; however, Na levels were highly increased under salt treatment, especially for MEL1 and LdG (13.2- and 5.3-fold, respectively) (Table 2). The K fruit concentration was significantly reduced only for MEL1 and ALM. Fruit mineral concentration for Ca, P, Fe, B, and Mn was different among genotypes at the control treatment and was not altered by the salt treatment except for the concentration of Mn, which was reduced in the case of MEL5 (Table 2). The concentrations of Mg and Zn were not significantly different among genotypes under control conditions, and although they became different under salt treatment, the differences were not enough to consider them different from their control values (Table 2).

Statistically significant correlations between ion accumulation in different organs were calculated (Table S1). A total of 18 correlations were found within fruit minerals, 17 were found within leaf minerals, and 12 were found within root minerals. More correlations were found between fruit and leaf (16) than between fruit and root (7) or leaf and root (14). However, root showed a smaller number of significant correlations indicating a differential performance under salt stress than fruit and leaf. As expected, negative correlations were found with Na and other main ions for plant metabolism as K, Mn, and Mg. When increasing Na in roots and leaves, K, Mn, and Mg levels decreased in both plant organs. On the contrary, when Na increased in the fruit, K also seemed to accumulate more in the fruit.

3.4. Fruit Antioxidant Accumulation

Total phenolic compounds (TPC) values did not show significant differences between genotypes within the same treatment or between control and treated plants, with values ranging from 7.42 mg g^{-1} dw for ALM in control conditions to 11.81 mg g^{-1} dw in ALM in treated plants. Control values ranged from 7.42 in ALM to around 8 in MEL5 and LdG and almost 10 mg g^{-1} dw for MEL1. Further, TPC obtained values under the salt treatment ranged from around 7.50 for MEL5 and LdG to around 11.5 mg g^{-1} dw for MEL1 and ALM.

Chlorogenic acid (CA) content was not significantly altered in fruit under salt stress for any of the genotypes tested. CA values ranged from 4.26 mg g^{-1} dw for LdS to 7.65 mg g^{-1} dw for MEL1, with no differences between genotypes. Under salinity conditions, CA values ranged from around 6 for MEL5, LdG, and Alm to 7.4 mg g^{-1} dw for MEL1.

3.5. Sugar Quantification

Sugar accumulation in fruit showed different performances depending mainly on the genotype (Figure 2). MEL1 fruit sugar content was not affected by the salt treatment. In the case of MEL5, glucose (GLU) contents were reduced under salt treatment (Figure 2a). Contrarily, LdG showed the highest values of GLU both for control and stress conditions. Fructose (FRU) levels in fruits were similar within genotypes, and only MEL5 showed a significant reduction in FRU accumulation under salt stress (Figure 2b). MEL5 and LdG were the most affected by salt, drastically reducing GLU production. MEL1 accumulated lower sucrose (SUC) values in treated and non-treated plants (Figure 2c). Genotypes generally increased SUC levels in fruits under salt stress; however, LdG showed higher production values under control conditions and were reduced under salt stress. Curiously,

ALM increased significantly SUC accumulation during salt treatment while it did not show modifications in FRU or GLU.

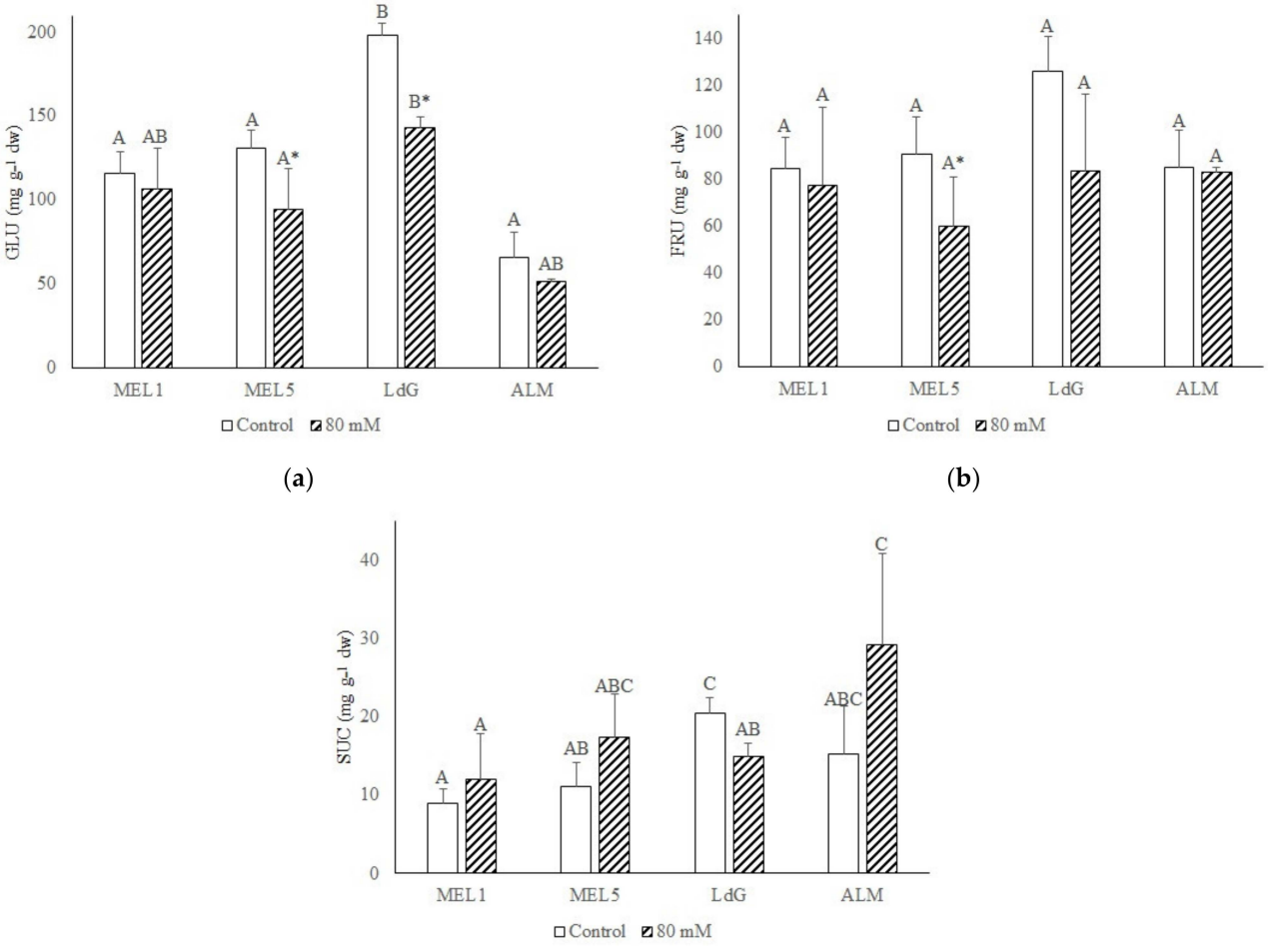

Figure 2. (**a**) Glucose (GLU), (**b**) fructose (FRU), and (**c**) sucrose (SUC) quantification (mean ± SD; n = 5) for *Solanum melongena* accessions under control and saline irrigation (80 mM) treatments. Different letters indicate statistically significant differences between genotypes ($p < 0.05$) within each treatment. The asterisk indicates statistically significant differences between treatments ($p < 0.05$) in the corresponding genotype, according to the Student–Newman–Keuls multiple range test.

4. Discussion

This work compares the fruit quality of four eggplant genotypes (*Solanum melongena* L.) under long-term salt stress. Salt has a great variety of effects on plant species, with a limitation in plant growth being the first indicator of stress [17,28]. However, as it has been previously reported, great stress is necessary for the eggplant cultivars to significantly reduce their growth parameters [29]. In fact, the capability of maintaining or even elongating primary and secondary roots [11] in response to drought has been noticed, as was observed in this work in some genotypes. In this regard, eggplants share some response mechanisms for drought and salinity, such as growth inhibition, ion movement alteration, and osmotic stress [17,29]. However, compared to other salt-tolerant species, such as quinoa (*Chenopodium quinoa*), *S. melongena* reduces plant biomass and limits its metabolism under salt stress with lower NaCl concentrations. Moreover, ion accumulation in quinoa is barely altered in salinity under moderate salt concentrations [30,31].

Fruit quality changes under abiotic stress are highly dependent on the genotype [32]. To determine whether fruit quality is affected in eggplant cultivars, a constant and long-

term 80 mM salt treatment was used in four *S. melongena* varieties in which mineral composition, phenolic compounds, and sugars were measured. Concentrations over 100 mM are considered lethal for the plants, as they lead to metabolism inhibition [33,34]. Thus, 80 mM was considered as moderate in this study.

Eggplants show a huge diversity in fruit morphology, including shape and size [5], which can explain the natural differences in fruit weight observed in this study. However, it is likely to find fruit weight differences due to salinity [11] that were not found in this study. Our hypothesis is that a longer or stronger salinity treatment and a large fruit set are necessary to induce significant changes in fruit weight.

Interestingly, there were no great changes in most mineral components analyzed, while there was significant diversity among the cultivars, as reported by previous authors [4]. The main affected ions were related to salt response, such as Na and K [14,17], and to cell signaling in root and leaf, such as P [35,36]. Ca deficiency can create some physiological disorders and depreciation of the fruits with the appearance of so-called blossom end rot [37]. Fortunately, the presence of Na did not affect the Ca accumulation in the fruit. Na accumulation in roots and leaves causes toxicity in the plant and leads to an alteration of the ion movement, which has been reported to be dependent on the genotype [9,20]. Regarding correlation data, the expected alteration of the main ion of plant nutrition and metabolism has been found as a reduction in K, Mn, and Mg when Na presence increased in plant organs. Curiously, fruits proved to have a different metabolism regarding ion accumulation, with an increase in both Na and K. One hypothesis could be the protection of the fruit and, thus, the seeds through the translocation of Na to the roots instead of relocation to non-photosynthetic or "sink" plant tissues such as flowers and fruits with the activation of HKT transporters as in other species, such as pepper [38]. Another alternative reported in tomatoes could be the overexpression of vacuolar Na^+/H^+ antiporters to sequester sodium into the vacuoles, avoiding the movement to other organs and tissues [39]. Ion transporter studies in fruit are rare or nonexistent and only reported for fruit development [40]. Nevertheless, it would be interesting to establish studies for Na and K transports in the fruit in response to salt stress and ion translocation.

Phenolic compounds are one of the main quality descriptors in eggplant fruit, specially chlorogenic acid, the main phenolic compound in unripe eggplant fruit. It has been reported by Martinez-Ispizua et al. [41] that the accumulation of phenolic compounds in eggplant fruit is highly dependent on the genotype. In our study, the cultivars tested were similar for the phenolics and minerals contents in the fruit. It has been demonstrated that environmental conditions, including abiotic stresses, could influence eggplant growth and composition and affect the fruit quality [42,43]. However, the accessions tested did not show differences in their phenolic and mineral composition in this experiment, as reported previously [44,45].

Sugars did not show huge changes under salt stress, differentiating eggplant from other Solanaceae species, such as tomato or pepper [13], and other species, like strawberry [14], especially on sucrose metabolism. A lack of response to the salt treatment was previously reported in eggplant [39] and can be explained by the fact that eggplant fruit is harvested when immature when starch has not been hydrolyzed. An increase in soluble solids such as total sugars has been observed in tomatoes treated with moderate salt stress due to what is known as the "concentration effect" or a different movement in the plant of assimilates [15]. In eggplant, differences between varieties on their sugar profile have been observed [41], and a higher sugar content has been described as a result of a selection process [46]. Sucrose synthase in coordination with sucrose phosphate synthase are described as important enzymes related to sugar accumulation in eggplant fruit, with high contents of fructose and glucose and low sucrose content indicating considerable invertase activity [47]. Also, the up-regulation of sucrose synthase under salt stress has been described in other species like tomatoes [12,48,49]. In our case, two genotypes reduced the quantity of monosaccharides, and one, ALM, increased the amount of the disaccharide sucrose, indicating activation of different metabolic pathways.

The maintenance of the quality of the fruit has been associated with more tolerant genotypes [50,51]. In this work, all genotypes showed a similar tolerance to salt, probably due to the moderate stress applied. Nevertheless, each genotype showed unique performances for the fruit composition and quality of analyzed traits. Special differentiated performance was observed in LdG, specifically in regard to sugars and chlorogenic acid. That means that there is genetic diversity to be explored in the quality response of eggplant to salt stress.

5. Conclusions

To summarize, eggplant genotypes show an intraspecific diversity in their response to salt irrigation. Nevertheless, little difference was found in fruit quality due to salt stress. These results were in consonance with small alterations in growth parameters, which were not remarkably affected in low salt concentrations and may be due to a partial tolerance to salinity of eggplant species. Moreover, as eggplant fruit is consumed unripe, inappreciable changes were seen in mineral and phenolic contents and very few in sugar content under mild salt stress. Altogether, these results indicate the resilience of eggplant in terms of fruit quality to the changing environment.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/agriculture14060871/s1, Table S1: Mineral correlations between plant organs.

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