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BIOACTIVE COMPOUNDS IN DIFFERENT MELON (*Cucumis melo* L.) GENOTYPES AND ONE CULTIVAR GROWN UNDER DEFICIT IRRIGATION AND SALT STRESS

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ABSTRACT

Drought and salinity are the most important abiotic factors limiting agricultural production. One of the effective ways to avoid their negative effects on plants is to determine the genotypes that will show resistance to these stress conditions. In addition, the gradual decrease in water resources in the world makes minimum water consumption important in agriculture. For this purpose, three different irrigation levels (I_{100}: control – 100% full irrigation, i.e. 0% deficit irrigation, I_{50}: 50% deficit irrigation, I_{25}: 25% deficit irrigation) were applied within the framework of water constraint, and NaCl was applied at the doses of S_0: 0 mM (control), S_{50}: 50 mM and S_{75}: 75 mM to create salt stress, and the experimental plots were designed according to the random plot experimental design with three replications and four plants in each replication. In the genotype × salinity interaction, compounds other than fumaric acid from organic acids formed significant interactions with genotypes YYU-4 and YYU-10. Among phenolic compounds, parameters other than total phenolic and antioxidant content formed significant interactions mainly with cv. Ananas. In the genotype × irrigation interaction, among organic acids, oxalic, succinic and fumaric acids and among phenolic compounds, only vanillic acid showed significant interactions particularly with genotypes YYU-1, YYU-10 and YYU-13. As a result of the study, it was concluded that the determined genotypes are prominent in terms of quality fruit production in saline and arid areas, and it is necessary to examine these genotypes using different parameters in different breeding studies.

Keywords: melon, deficit irrigation, salt stress, organic acids, phenolics

INTRODUCTION

Abiotic stress has become a significant risk for food security and is a leading cause of widespread crop and agricultural product loss worldwide. It is estimated that approximately 50% of major agricultural products are lost due to various abiotic stress factors. Under abiotic stress conditions such as drought, heavy metals, salinity, extreme temperatures, and UV radiation, plants produce higher levels of polyphenols, including phenolic acids and flavonoids, which help them cope with environmental constraints. Plants detect stress signals through receptors and activate protective mechanisms to withstand abiotic stresses. These protective mechanisms involve the accumulation of defensive metabolites, such as phenolics, terpenes, and alkaloids, with phenolics playing a vital role in plant survival under various abiotic stresses [Ahlawat et al. 2024]. Vegetables contain variable amounts of organic and phenolic acids depending on the maturity, exposure to biotic and abiotic stresses, and cultivar [Rashmi et al. 2020].

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While extensive research has been conducted on the physiological effects of salinity and drought, relatively little data is available on the antioxidant enzyme responses [Waśkiewicz et al. 2013]. Salinity stress typically creates ionic and osmotic pressure in plants, leading to the accumulation or reduction of certain biochemicals [Parida and Das 2005]. Many previous studies have shown that changes in the levels of phenolic and organic compounds in plants enhance their defense mechanisms against stress, particularly oxidative stress induced by high salinity concentrations [Wahid and Ghazanfar 2006]. Water stress is one of the most common and dramatic environmental stresses affecting plant growth and reducing crop yield in many cultivated areas. The effects of drought stress on plant growth and yield depend on genotype sensitivity, phenological stage, plant organs (leaves and fruits), and the intensity and duration of the stress [Marjanović et al. 2012, Mirás-Avalos and Intrigliolo 2017]. Despite the adverse effects of water deficit, some studies have reported positive impacts on product quality by stimulating the metabolism of phytochemicals through the activation of secondary metabolite biosynthesis [González-Chavira et al. 2018]. Water deficiency conditions often determine the production of fruits with higher antioxidant activity due to decreased enzymatic activity and increased levels of vitamin C and total phenolic content [Pék et al. 2014]. Consequently, it can be hypothesized that an increase in polyphenols may be achieved using stress-tolerant species [De Abreu and Mazzafera 2005].

In this study, it was hypothesized that under varying levels of salt and water stress, specific melon genotypes will exhibit distinct responses in terms of bioactive compound accumulation, such as phenolic and organic acids. It was predicted that higher stress conditions lead to an increase in the content of certain bioactive compounds, particularly those involved in antioxidant activity, as a defense mechanism. Furthermore, it was expected that some melon genotypes would show better tolerance by maintaining higher levels of these compounds, making them more suitable for cultivation in saline and drought-prone environments.

MATERIAL AND METHODS

Agricultural practices. In the salt stress study, the melon genotypes YYU-1, YYU-4, YYU-10, YYU-18, CU-196 and the cultivar Ananas were used as plant materials (Fig. 1). For the limited irrigation study, the genotypes YYU-1, YYU-10, YYU-13, YYU-25, CU-196, and the cultivar Ananas were selected. High-performance liquid chromatography (HPLC)

Fig 1. Images of melon fruits used in the study

analysis of the fruits identified five organic compounds, i.e., malic acid, oxalic acid, citric acid, succinic acid, and fumaric acid. This study involved six melon genotypes (YYU) collected from the Van Lake Basin, along with one genotype and one cultivar (Ananas and CU-196) previously determined as sensitive or tolerant to salt and water stress based on prior research [Kuşvuran et al. 2007, Kuşvuran et al. 2008, Kuşvuran et al. 2011, Kıran et al. 2014] (Tab. 1).

The seeds of the selected genotypes were sown on May 12 in 45 mm pots filled with a sterilized mixture of peat and perlite (2 : 1 ratio). Throughout the seedling period, essential care practices, including irrigation, fertilization, and control of diseases and pests, were diligently maintained. On June 28, the seedlings were transplanted into 12-liter drain-less pots filled with the same sterilized peat and perlite mixture, following a random plot design.

Salt stress was applied using three different concentrations of NaCl to evaluate the impact of abiotic stress on the plants: 0 mM (control), 50 mM, and 75 mM, which were applied three times in three weeks. For drought stress, water deficit treatments were applied at three levels: 0% (control), 25%, and 50% water restriction. The stress treatments were initiated at the flowering stage, specifically 20 days after the plants were transplanted. Each treatment was replicated three times, with three plants per replication.

Before the planned irrigations, water was applied to all pots up to the pot capacity. The amount of irrigation water applied in each irrigation was calculated by the following equation (1):

$$I = ((Wi - 1) - Wi) \cdot IR \quad (1)$$

where: I is the amount of irrigation water (mL), W_{i-1} and W_i are the pot weights in three or four days (kg), IR is the irrigation rate or a conversion factor to adjust for specific conditions.

In non-climacteric melon (*Cucumis melo* L.) genotypes, the optimal harvest time was determined by the changes in external color, with the rind turning lighter or developing a yellowish hue, depending on the variety. Moreover, the drying of the tendril and stipules at the point where the fruit stem attaches to the vine was an important harvest criterion. The biochemical analyses of the fruit samples were conducted at the fruit maturity stage to determine the changes in biochemical composition under stress conditions. The study was conducted over two months, and both salt and drought stress treatments were applied simultaneously to evaluate their individual and interactive effects on the plants. Given the known greater impact of drought stress compared to salt stress, the results were closely monitored throughout the experimental period to capture any significant variations in plant responses.

Chemicals. In the present study, chemicals with analytical purity were used. Organic acid standards (citric acid, tartaric acid, oxalic acid, malic acid, succinic acid and fumaric acid) were obtained from Sigma-Aldrich (St. Louis, MO, USA). The other chemicals were obtained from Merck (Darmstadt, Germany).

Extraction of organic acids and determination by HPLC. The method by Bevilacqua and Califano [1989] was modified for organic acid extraction. One gram of

Table 1. Identification of melon varieties and genotypes utilized in the study

Genotype	Salt stress	Deficit irrigation	Provided location information
YYU-1	×	×	Türkiye–Van–Sihke–Kıratlı
YYU-4	×	–	Türkiye–Van–Sihke–Kıratlı
YYU-10	×	×	Türkiye–Van–Sihke–Merkez
YYU-13	–	×	Türkiye–Van–Sihke–Kıratlı
YYU-18	×	–	Türkiye–Van–Cakirbey
YYU-25	–	×	Türkiye–Van–Erçek–Irgatlı
Ananas	×	×	Türkiye–Standard Cultivar
Cu-196	×	×	Türkiye– Midyat

the fruit samples was transferred to centrifuge tubes, and 10 mL of 0.009 H_2SO_4 was added and homogenized (Heidolph Silent Crusher M, Germany). It was then mixed on a shaker (Heidolph Unimax 1010, Germany) for 1 hour and centrifuged at 15000 rpm for 15 min. The aqueous fraction separated by centrifugation was first passed through coarse filter paper, then through a 0.45 µm membrane filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA) twice and finally through a SEP-PAK C18 cartridge. The concentration of organic acids was determined by HPLC using an Aminex column (HPX-87H, 300 mm × 7.8 mm, Bio-Rad) fitted on an Agilent 1100 series HPLC G 1322 A, Germany) [Bevilacqua and Califano 1989]. Organic acids were detected at 214 and 280 nm wavelengths.

Extraction of phenolic compounds and determination by HPLC. For the separation of phenolic compounds by HPLC, the method described by Rodriguez-Delgado et al. [2001] was modified and used. One gram of the fruit samples was taken and homogenized by adding 10 mL of methanol. After homogenizing, the samples were centrifuged at 15 000 rpm for 15 min. The upper part was then filtered with 0.45µm millipor filters (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA) and injected into the HPLC system (gradient). Chromatographic separation was performed on an Agilent 1100 (Agilent) HPLC system using a DAD detector (Agilent. USA) and a 250 × 4.6 mm, 4 µm ODS column (HiChrom, USA). Solvent A methanol-acetic acid-water (10 : 2 : 88), and Solvent B methanol-acetic acid-water (90 : 2 : 8) were used as mobile phase, and a gradient elution program was applied. Separation was performed at 254 and 280 nm. The flow rate was 1mL/min, and the injection volume was 20 µL.

Total phenolic contents (TP). The amount of total phenolic compounds was adapted according to Jang et al. [2007]. Each sample (5 g) was subjected to extraction with 100 mL of methanol/water (80/20 v/v) for 1 hour. Then, the solid was separated from the extract by vacuum filtration and a volume of 0.15 mL was added to 0.15 mL of a Folin Ciocalteu reagent (1 : 10). The mixture was allowed to stand at 25 °C for 3 min before 0.30 mL of saturated sodium carbonate solution was added. After standing at room temperature for 30 min, absorbance readings were carried out at 725 nm using a UV-Vis spectrophotometer. The results were expressed as gallic acid mg (GAE)/100 g^{-1} FW.

Total antioxidant activity (TAC). Ferric reducing antioxidant power (FRAP) method was used to determine the antioxidant activity [Benzie and Strain 1996]. The absorbances of the prepared solutions were read at 593 nm wavelength in a spectrophotometer, and the antioxidant activity values were given as µmol Trolox equivalent (TE) g^{-1}.

Statistical analysis. The data obtained in the study were evaluated using a two-way analysis of variance (ANOVA) with the SPSS statistical program at a significance level of $P \leq 0.05$. In the data analysis, the differences between statistically significant means were grouped according to the Duncan Multiple Comparison Test.

RESULTS AND DISCUSSION

Effect of salt stress on organic acids

In six melon genotypes and one cultivar subjected to 50 and 75 mM salt doses, six organic acids such as malic, oxalic, citric, succinic, tartaric and fumaric, that determine the fruit quality were determined. Fruits can be roughly divided into tartaric, malate and citrate acid types according to the dominant organic acid [Ma et al. 2022]. It was stated that citric acid was the dominant acid among organic acids in melon [Özbek 2021]. The present study determined that the most abundant organic acids in melon fruits under both stress conditions were citric and malic acid, respectively, and fumaric acid was determined in the lowest amount. In the data obtained concerning the genotypes exposed to salt stress, significant differences were obtained for all organic compounds except fumaric acid. The differences between salt doses were significant for all organic compounds except succinic and fumaric acid (Tab. 2). Genotype YYU-4 showed the highest mean data for malic acid, and significant interactions were found between salt applications and genotypes. In this group of interactions, YYU-4 showed the highest malic acid content of 1926.9 mg kg^{-1} FW in the control group. In parallel with the increase in salt stress, the malic acid content of the genotypes decreased. The highest mean oxalic acid content was determined in YYU-1 (17.1 mg kg^{-1} FW). Among the treatments, the oxalic acid ratio increased in plants given the S_{75}

Table 2. Organic acid contents of melon fruits grown under salt stress conditions (mg kg^{-1} FW)

Genotypes	Salt doses	Malic	Oxalic	Citric	Succinic	Tartaric	Fumaric
1	S_0	375.9 ±78.3e	6.5 ±1.7 cd	1600.6 ±24.1c-f	71.3 ±24.8c-e	10.7 ±3.9b-d	1.3 ±0.3
	S_{50}	370.1 ±68.6e	6.5 ±0.2cd	1919.9 ±149.1a-d	230.5 ±32.8a	13.3 ±0.4a-c	2.5 ±0.3
	S_{75}	355.9 ±16.1e	38.3 ±1.3a	2425.4 ±258.5ab	39.8 ±13.5e	12.2 ±1.2a-c	2.4 ±0.8
4	S_0	1926.9 ±63.5a	17.7 ±7.6b	1086.7 ±157.8f-h	139.9 ±30.4bc	16.9 ±0.8a	4.6 ±1.3
	S_{50}	409.9 ±42.9de	6.0 ±0.1cd	2615.2 ±438.1a	134.3 ±15.5b-d	5.6 ±1.4d-f	3.4 ±1.0
	S_{75}	287.6 ±75.2e	3.8 ±0.7d	1964.9 ±474.8a-e	80.2 ±15.2c-e	5.2 ±2.2d-f	1.7 ±0.4
10	S_0	1004.3 ±231.4b	2.7 ±1.4d	1446.5 ±96.4d-g	98.7 ±14.0b-e	8.5 ±4.1c-e	3.1 ±1.3
	S_{50}	643.6 ±136.0b-e	7.1 ±0.7cd	1884.6 ±90.3b-e	137.8 ±59.2bc	13.1 ±2.4a-c	2.9 ±0.7
	S_{75}	435.1 ±182.7de	7.7 ±0.2cd	1178.7 ±173.0e-h	171.6 ±55.8ab	15.1 ±1.2ab	1.7 ±0.6
18	S_0	498.5 ±69.3c-e	6.5 ±0.3cd	2183.2 ±274.3a-c	87.7 ±12.9c-e	11.7 ±2.6a-c	1.6 ±0.8
	S_{50}	285.9 ±35.2e	4.4 ±0.3d	2038.1 ±275.0a-e	48.3 ±11.8e	3.8 ±0.8ef	3.8 ±0.0
	S_{75}	380.7 ±146.0e	5.2 ±0.6d	1439.9 ±189.8d-g	51.9 ±19.1de	5.5 ±1.2d-f	2.6 ±0.9
Ananas	S_0	319.6 ±42.6e	12.1 ±1.5bc	689.1 ±6.5hi	25.1 ±2.4e	9.4 ±2.0b-e	1.9 ±0.8
	S_{50}	588.1 ±25.2c-e	1.9 ±0.2d	1551.1 ±183.6c-f	14.6 ±1.2e	5.3 ±0.9d-f	4.2 ±1.3
	S_{75}	358.1 ±47.2e	2.4 ±0.5d	792.2 ±47.4g-i	16.6 ±2.8e	1.7 ±0.0f	1.2 ±0.3
CU-196	S_0	536.2 ±147.3c-e	2.4 ±0.3d	158.9 ±12.3i	35.4 ±10.0e	3.8 ±0.3ef	4.4 ±2.2
	S_{50}	892.2 ±157.6bc	4.2 ±1.4d	390.2 ±85.0i	32.1 ±12.1e	4.0 ±0.9ef	1.0 ±0.5
	S_{75}	806.4 ±260.4b-d	2.8 ±0.2d	265.1 ±46.6i	66.2 ±29.8c-e	1.3 ±0.0f	4.3 ±2.7
Mean							
Genotype -1		367.3 ±30.5b	17.1 ±5.3a	1981.9 ±163.3a	113.9 ±32.1a	12.1 ±1.2a	2.1 ±0.3
Genotype -4		874.8 ±265.4a	9.1 ±3.1b	1889.0 ±293.1a	118.1 ±14.4a	9.2 ±2.1ab	3.2 ±0.6
Genotype -10		694.3 ±125.3a	5.8 ±0.9c	1503.3 ±120.5b	136.0 ±26.01a	12.2 ±1.7a	2.6 ±0.5
Genotype -18		388.4 ±56.8b	5.4 ±0.4c	1887.1 ±168.9a	62.6 ±9.8b	7.0 ±1.5bc	2.6 ±0.5
Ananas		421.9 ±46.3b	5.5 ±1.7c	1010.8 ±146.5c	18.8 ±2.0b	5.5 ±1.3cd	2.4 ±0.6
CU-196		744.9 ±111.4a	3.2 ±0.5c	271.4 ±43.7d	44.6 ±11.1b	3.0 ±0.5d	3.2 ±1.2
Mean							
S_0		776.9 ±142.2a	8.0 ±1.7a	1194.2 ±168.1b	76.3 ±11.3	10.2 ±1.3a	2.8 ±0.5
S_{50}		531.6 ±58.6b	5.0 ±0.5b	1733.2 ±183.7a	99.6 ±20.9	7.5 ±1.1b	3.0 ±0.4
S_{75}		437.3 ±65.4b	10.0 ±3.1a	1344.4 ±192.6b	71.0 ±15.4	6.8 ±1.3b	2.3 ±0.5
$P^{Genotype}$		<.0001	<.0001	<.0001	<.0001	<.0001	0.7864
P^{Salt}		<.0001	0.0004	0.0005	0.1379	0.0092	0.5839
P^{GxS}		<.0001	<.0001	0.0034	0.0017	0.0007	0.1549

dose. Significant interactions between salt treatments and genotypes were observed for oxalic acid values, and YYU-1 showed the highest content of this organic acid of 38.3 mg kg^{-1} FW when treated with the S_{75} dose. The highest average citric acid amount was determined in YYU-4. Among the salt treatments, there was an increase in salt stress at the S_{50} dose. For significant interactions between treatments and geno-

types, the S_{50} dose applied to YYU-4 was determined as the dose causing the highest increase in the citric acid content of 2615. 2 mg kg^{-1} FW. Recent studies have demonstrated that exogenous citric acid/citrate (CA) can enhance abiotic stress tolerance in plants. In certain plant species such as *Helianthus annuus* (sunflower), *Solanum lycopersicum* (tomato), *Acacia ampliceps*, and *Trigonella foenum-graecum*, citric acid levels increased following exposure to salinity for periods ranging from seven days to four weeks [Abbas et al. 2015, Kang et al. 2019, Mickky et al. 2019]. YYU-10 showed the highest increases in succinic acid and tartaric acid contents. The differences obtained for succinic acid were not significant, and the control group had the highest mean content of tartaric acid. Significant interactions occurred for both components, and the highest contents were obtained for succinic acid in genotype YYU-1 treated with the S_{50} dose (230.5 mg kg^{-1} FW) and for tartaric acid at in genotype YYU-4 cultivated with the control salt dose – S_0 (16.9 mg kg^{-1} FW). Zamljen et al. [2022], in their study in which different chilli genotypes were exposed to 20 and 40 mM salt stress, reported that the contents of organic compounds examined in the pericarp, placenta and seed decreased in all genotypes except the pericarp of the 'Somborka' genotype. However, when the pericarps of the genotypes were examined, it was observed that increases in organic acid contents varied depending on the salt doses.

Effect of salt stress on phenolics

Phenols are powerful antioxidants in plants and help reduce the negative effects of ROS in cells caused by salt stress [Bistgani et al. 2019]. In a salt stress study, in a group of phenolic compounds, gallic, vanillic, ferulic and ferulic acids, quercetin, total phenolic and antioxidant contents were determined (Tab. 3). Significant interactions were determined for parameters other than total phenolic and antioxidant contents. For gallic acid, the differences in the mean data obtained from genotypes and treatments were not found to be significant, but significant interactions were found for the genotype × salinity relationship. The S_{75} treatment of YYU-4 (334.2 mg kg^{-1} FW) produced the highest gallic acid content. The Ananas cultivar showed the highest average content of vanillic acid. In the genotype × salinity relationship, significant interactions were observed in the Ananas cultivar (3802.5 mg kg^{-1} FW) grown at S_0. Ferulic acid values between genotypes and between treatments were not significant. Th genotype × salinity interaction was significant, and genotype YYU-4 exposed to the S_{75} dose (186.9 mg kg^{-1} FW) showed the highest ferulic acid content. When the data of the quercetin compound in salt, genotype and genotype × salinity interactions were analyzed, it was observed that although significant differences occurred, values close to each other were observed. Although total phenolic and antioxidant contents in the fruits did not show significant relationships, genotype YYU-4 showed high contents of total phenolic compounds. The diversity and contents of phenolics and flavonoids vary depending on the plant species, varieties and cultivars [Khoshbakht et al. 2018]. In Brassica species, the contents of these compounds tend to increase when plants are exposed to stress [Del Carmen Martínez-Ballesta et al. 2013]. In a salt stress study on broccoli, the highest gallic, vanillic and ferulic acid contents were obtained at 100 mM and 150 mM salt doses [Haghighi et al. 2023]. Zamljen et al. [2022] reported that phenolic compound contents increased with increasing salt concentrations in chilli genotypes. In a study on salt stress applied to beans, Telesiński et al. [2008] observed an increase in both total phenolic and flavonoid compound contents in bean tissues after the 28th day of the experiment. However, they noted that despite a decrease in total phenolic content on the 14th day, the flavonoid content increased with rising salinity. Additionally, the total phenolic and flavonoid compound contents remained stable under increased salt stress on the 21st day. The effects of varying levels of salt stress on the phenolic antioxidant system have also been investigated by Agastian et al. [2000], Yuan et al. [2010], and Rezazadeh et al. [2012]. In mulberry genotypes analyzed under low salt application, total phenolic content decreased in all cases [Agastian et al. 2000] but increased under higher salinity. However, the direction of these changes was the opposite in radish sprouts [Yuan et al. 2010]. Rezazadeh et al. [2012], in their study on the effect of salinity on the phenolic content of artichoke, gave similar results to those recorded by Yuan et al. [2010]. While moderate salinity significantly increased total phenolic and flavonoid

Table 3. Phenolic and antioxidant compound contents of melon fruits grown under salt stress conditions

Genotypes	Salt doses	Gallic (mg kg^{-1} FW)	Vanillic (mg kg^{-1} FW)	Ferulic (mg kg^{-1} FW)	Quercetin (mg kg^{-1} FW)	Total phenolics (mg GAE 100 g^{-1} FW)	Total antioxidant (Trolox µmol TE g^{-1} FW)
1	S_0	154.3 ±10.3cd	3028.6 ±1.9b	164.6 ±0.8b-d	37.5 ±0.2a	12.8 ±0.7	21.7 ±2.0
	S_{50}	219.4 ±21.8a-d	2606.5 ±9.9de	170.7 ±5.6a-c	33.6 ±0.1d	11.1 ±0.0	26.6 ±3.3
	S_{75}	240.2 ±37.3a-d	2692.8 ±39.0d	173.3 ±12.6a-c	33.7 ±0.1d	13.6 ±2.5	22.0 ±1.1
4	S_0	196.6 ±4.0b-d	2569.8 ±5.7e	154.9 ±1.1cd	33.7 ±0.1d	15.6 ±1.1	24.1 ±1.3
	S_{50}	200.0 ±12.1b-d	2587.8 ±14.7e	160.3 ±3.8cd	33.7 ±0.2d	13.4 ±2.1	20.0 ±1.0
	S_{75}	334.2 ±78.4a	2646.5 ±40.5de	186.9 ±17.6a	34.3 ±0.0cd	12.4 ±0.1	21.3 ±1.3
10	S_0	271.9 ±24.2a-d	2471.8 ±68.6f	169.1 ±12.3a-c	28.0 ±1.5e	14.8 ±2.0	23.6 ±2.0
	S_{50}	194.8 ±31.0b-d	2313.5 ±4.7g	142.8 ±0.2d	26.4 ±1.2f	13.6 ±0.3	26.0 ±3.7
	S_{75}	230.4 ±36.7a-d	2335.8 ±15.1g	165.3 ±7.3b-d	25.0 ±0.6f	11.3 ±0.1	21.7 ±1.9
18	S_0	310.2 ±43.6ab	3026.1 ±24.0b	164.9 ±0.3b-d	37.0 ±0.0ab	11.2 ±0.8	28.0 ±6.7
	S_{50}	207.5 ±20.3a-d	3018.2 ±12.5b	163.7 ±0.7b-d	37.2 ±0.1ab	13.2 ±0.6	21.1 ±0.1
	S_{75}	198.6 ±10.8b-d	2991.6 ±11.8b	163.1 ±0.3b-d	36.9 ±0.1ab	12.2 ±0.7	23.4 ±2.0
Ananas	S_0	144.7 ±14.2d	3802.5 ±6.6a	185.3 ±1.4ab	34.8 ±0.0cd	13.8 ±1.0	22.9 ±0.2
	S_{50}	229.2 ±32.7a-d	3030.8 ±5.8b	164.9 ±4.0b-d	37.1 ±0.1ab	14.3 ±0.2	20.9 ±1.2
	S_{75}	166.8 ±22.7cd	2991.6 ±8.0b	161.1 ±0.8cd	37.1 ±0.1ab	12.5 ±1.2	19.7 ±1.7
CU-196	S_0	218.5 ±23.1a-d	2779.9 ±47.6c	161.5 ±2.7cd	37.5 ±0.0a	11.4 ±0.5	19.7 ±0.8
	S_{50}	283.1 ±99.0a-c	2782.6 ±40.6c	164.1 ±6.0b-d	38.0 ±0.2a	10.1 ±0.8	17.8 ±0.3
	S_{75}	200.7 ±9.0b-d	2686.5 ±29.7d	161.5 ±0.9cd	35.6 ±1.2bc	12.1 ±0.8	18.7 ±1.3
Mean							
Genotype -1		204.6 ±18.2	2775.1 ±65.4c	169.5 ±4.2	34.9b ±0.6	12.5 ±0.8ab	23.4 ±1.4a
Genotype -4		243.6 ±32.3	2601.4 ±17.1d	167.3 ±7.2	33.9c ±0.1	13.8 ±0.8a	21.8 ±0.9ab
Genotype -10		232.4 ±19.1	2373.7 ±32.0e	159.1 ±5.8	26.4d ±0.7	13.2 ±0.8a	23.8 ±1.5a
Genotype -18		238.7 ±22.9	3011.1 ±10.0b	163.9 ±0.4	37.0a ±0.1	12.2 ±0.5ab	24.2 ±2.3a
Ananas		180.3 ±17.6	3274.9 ±132.0a	170.4 ±3.1	36.3a ±0.4	13.5 ±0.5a	21.2 ±0.8ab
CU-196		234.1 ±32.0	2749.7 ±25.5c	162.4 ±2.0	36.9a ±0.5	11.2 ±0.5b	18.8 ±0.5b
Mean							
S_0		216.0 ±16.6	2946.4 ±106.5a	166.7 ±2.9	34.7 ±0.8a	13.2 ±0.5	23.3 ±1.2
S_{50}		222.3 ±17.4	2723.2 ±61.8b	161.1 ±2.5	34.2 ±1.0ab	12.6 ±0.5	22.1 ±1.1
S_{75}		228.5 ±18.8	2724.1 ±55.2b	168.5 ±3.9	33.7 ±1.0b	12.4 ±0.4	21.2 ±0.7
$P^{Genotype}$		0.2965	<.0001	0.2684	<.0001	0.0652	0.0635
P^{Salt}		0.8507	<.0001	0.1416	0.0142	0.3655	0.2750
P^{GxS}		0.0278	<.0001	0.0127	<.0001	0.1830	0.5177

contents, further increases in salinity led to a decrease in phenolic compound contents in artichoke leaves. In the current study, although no significant differences were observed in total phenolic and antioxidant values, general decreases were noted as salt stress increased. According to Waśkiewicz et al. [2013], it is difficult to directly compare the results of studies examining the effects of salt stress on phenolic content in vegetables and fruits. This is because researchers apply various experimental conditions (source of salt stress, salt doses, and treatment duration), and the phenolic profile is examined in different materials (leaves, roots, fruits). Therefore, the contents of total phenolic acids and/or flavonoids show significant variation among species [Navarro et al. 2006, Lopez-Berenguer et al. 2009].

Effect of drought on organic acids

Analyzing the irrigation × genotype relationship, significant differences were observed between genotypes in a malic acid content in which no significant interactions occurred, and YYU-1 had the highest content. Significance was found between irrigation treatments, and the malic acid content obtained from I_{25} treatment was found to be the highest. Oxalic acid values between genotypes and between treatments were found to be significant. Irrigation × genotype interactions also showed significant differences. For this organic compound, genotype YYU-13 exposed to I_{25} limited irrigation, showed the most desirable interaction (44.8 mg kg^{-1} FW) (Tab. 4). Seymen et al. [2021] obtained the highest malic acid content from I_{100} full irrigation level in their limited irrigation studies in which they grafted different plant materials on different watermelon rootstocks. In addition, malic acid values increased with increasing irrigation levels and the lowest malic acid content was obtained from variant I_0, which was not irrigated. The researchers obtained the highest citric acid content from I_0 when irrigation levels were taken into consideration and stated that citric acid increased with increasing irrigation levels. In the current study, there was no statistical significance in terms of citric acid at different irrigation levels. Analyzing the citric acid data of the fruits were, the differences between the genotypes showed significance, and YYU-13 showed the highest citric acid content (2491.3 mg kg^{-1} FW). The highest citric acid content (1519.4 mg kg^{-1} FW) was determined at I_{50} drought level (Tab. 4). According to Tahjib-Ul-Arif et al. [2021], several studies on different plant species have shown that under drought stress, endogenous CA levels increased significantly in tomato, *Gossypium hirsutum*, *Clusia* sp., and *Aptenia cordifolia*, while the levels remained unchanged in *Solanum tuberosum* (potato). Özbek [2021] reported that different results were obtained for different melon varieties and irrigation levels and the highest citric acid content was obtained from 40% restricted irrigation (3.23 mg g^{-1}). In the current study, the highest succinic acid content (474.2 mg kg^{-1} FW) was obtained in genotype YYU-10 grown under the I_{25} restricted water dose in the irrigation × genotype interactions (Tab. 4). Significance was also found between genotypes and irrigation treatments. For fumaric acid, genotype YYU-1 was found to have the highest content of this compound. Studies on the effect of water stress have shown that sugar and acid contents in different fruits change under different intensities of water stress [Ma et al. 2022]. Ussahatanonta et al. [1996] reported that malic acid and tartaric acid contents increased by 23.9% and 16.6% in Cabernet sauvignon grapes treated with water and nutrient sufficiency, respectively. Cholet et al. [2016] determined the tartaric acid content in Ugni blanc grape berries under warmer-dry and cooler-humid climatic conditions and reported that the tartaric acid content of the fruit obtained in the warmer and drier climate was significantly higher than that in the cooler and wetter climate. In this study, it was observed that organic acid contents increased under restricted irrigation conditions compared to the control. Under salt stress conditions, increases were observed in S_{50} and S_{75} treatments except for malic and tartaric acids.

Effect of drought on phenolics

In the water restriction study, four phenolic compounds, i.e. gallic, vanillic and ferulic acids and quercetin, were determined (Tab. 5). The highest gallic acid content (261.8 mg kg^{-1} FW) was found in YYU-25. Genotype × irrigation interaction did not cause significant differences for gallic acid. No significant differences were found between irrigations. However, I_{50} restricted irrigation dose produced the high-

Table 4. Organic acid contents (mg kg^{-1} FW) of melon fruits grown under restricted irrigation conditions

Genotypes	Irrigations	Malic	Oxalic	Citric	Succinic	Fumaric
1	I_{100}	1040.2 ±297.0	14.2 ±4.9cd	570.7 ±6.6	144.9 ±40.9bc	6.4a ±2.5a-d
	I_{50}	509.7 ±76.2	6.1 ±1.1d-f	1836.6 ±362.7	37.6 ±16.8c	3.00 ±0.8c-e
	I_{25}	1301.3 ±228.1	6.7 ±0.9d-f	1824.3 ±587.0	54.8 ±2.6c	9.4 ±3.4a
10	I_{100}	883.7 ±226.0	9.0 ±2.0d-f	2893.5 ±1083.9	193.2 ±54.5b	5.7 ±1.5a-d
	I_{50}	366.9 ±15.3	6.7 ±2.7d-f	1681.3 ±148.1	29.1 ±8.2c	2.6 ±0.3de
	I_{25}	751.6 ±132.2	8.6 ±0.5d-f	1735.6 ±4.5	474.2 ±142.5a	5.4 ±2.4a-e
13	I_{100}	590.8 ±48.8	9.4 ±1.5d-f	2684.1 ±58.1	55.3 ±27.6c	2.3 ±0.5de
	I_{50}	453.5 ±33.8	11.9 ±3.4c-f	2424.4 ±616.9	41.8 ±15.2c	8.4 ±0.7ab
	I_{25}	734.6 ±177.0	44.8 ±1.1a	2365.5 ±282.9	16.3 ±2.6c	3.9 ±0.0b-e
25	I_{100}	255.9 ±38.0	7.4 ±0.9d-f	1822.1 ±356.3	80.3 ±14.6bc	6.0 ±2.5a-d
	I_{50}	304.4 ±72.4	19.6 ±5.5bc	1526.2 ±195.3	15.2 ±5.0c	7.7 ±0.2a-c
	I_{25}	292.7 ±57.3	26.7 ±0.4b	1384.4 ±324.6	12.8 ±4.5c	3.9 ±1.3b-e
Ananas	I_{100}	319.6 ±42.6	12.1 ±1.5c-f	689.1 ±6.5	25.1 ±2.4c	1.9 ±0.8de
	I_{50}	319.7 ±12.0	6.4 ±1.1d-f	1224.8 ±93.2	15.8 ±2.8c	2.4 ±0.1de
	I_{25}	626.3 ±10.5	9.00 ±0.3d-f	1073.4 ±79.4	44.2 ±4.8c	2.3 ±0.1de
CU-196	I_{100}	641.9 ±126.3	13.8 ±5.1c-e	114.4 ±46.2	41.5 ±17.0c	1.3 ±1.0de
	I_{50}	567.0 ±71.2	5.2 ±0.2ef	423.3 ±117.6	28.6 ±3.3c	8.2 ±1.7ab
	I_{25}	884.1 ±185.2	5.1 ±0.9f	277.4 ±133.2	33.0 ±1.0c	0.4 ±0.0e
Mean						
Genotype-1		950.4 ±160.4a	9.0b ±2.0b	1410.5 ±289.4c	79.1 ±21.0b	6.2 ±1.5a
Genotype-10		667.4 ±108.4b	8.1b ±1.1b	2103.5 ±372.6ab	232.2 ±78.5a	4.6 ±1.0a-c
Genotype-13		593.0 ±67.4bc	22.0a ±5.8a	2491.3 ±202.6a	37.8 ±10.8b	4.9 ±0.9a-c
Genotype-25		284.4 ±29.7d	17.9a ±3.2a	1577.6 ±163.4bc	36.1 ±12.0b	5.9 ±1.0ab
Ananas		421.9 ±52.8cd	9.1b ±1.0b	995.8 ±87.2c	28.3 ±4.5b	2.2 ±0.2c
CU-196		697.6 ±83.0b	8.0b ±2.1b	271.7 ±69.2d	34.4 ±5.3b	3.3 ±1.4bc
Mean						
I_{100}		622.0 ±88.1a	11.0b ±1.2b	1462.3 ±305.1	90.0 ±18.1a	3.9 ±0.8
I_{50}		420.2 ±30.1b	9.3b ±1.6b	1519.4 ±183.2	28.0 ±4.3b	5.4 ±0.7
I_{25}		765.1 ±89.8a	16.8a ±3.5a	1443.4 ±190.2	105.9 ±44.8a	4.2 ±0.9
$P^{Genotype}$		<.0001	<.0001	<.0001	<.0001	0.0175
$P^{Irrigation}$		0.0003	<.0001	0.9336	0.0031	0.2125
P^{GxI}		0.1723	<.0001	0.1160	<.0001	0.0016

Table 5. Phenolic and antioxidant compound contents of melon fruits grown under restricted irrigation conditions

Genotypes	Irrigations	Gallic (mg kg^{-1} FW)	Vanillic (mg kg^{-1} FW)	Ferulic (mg kg^{-1} FW)	Quercetin (mg kg^{-1} FW)	Total phenolics (mg GAE 100 g^{-1} FW)	Total antioxidant (Trolox µmol TE g^{-1} FW)
1	I_{100}	114.9 ±17.9	4870.8 ±2.0a	215.2 ±4.9	25.1 ±0.4	11.5 ±1.7	23.4 ±2.2
	I_{50}	170.3 ±16.7	4655.8 ±17.0b	224.1 ±8.1	25.5 ±6.7	8.9 ±0.8	21.9 ±2.2
	I_{25}	155.7 ±3.2	4746.1 ±70.7ab	208.6 ±0.6	26.0 ±0.1	9.3 ±0.8	23.5 ±1.0
10	I_{100}	124.6 ±24.3	4632.9 ±13.7b	199.3 ±0.7	26.6 ±0.2	9.9 ±1.3	24.2 ±2.8
	I_{50}	140.6 ±14.5	4625.3 ±0.9 b	201.3 ±0.9	26.8 ±0.1	12.4 ±0.2	19.7 ±0.4
	I_{25}	137.4 ±21.0	4620.4 ±1.9 b	201.6 ±1.4	26.6 ±0.1	10.2 ±0.6	21.9 ±0.9
13	I_{100}	144.3 ±6.0	4628.0 ±1.1 b	202.1 ±2.0	27.2 ±0.1	10.2 ±1.2	25.8 ±1.5
	I_{50}	246.0 ±52.4	3971.7 ±11.8d	192.7 ±2.4	32.0 ±2.1	11.5 ±1.1	18.1 ±0.8
	I_{25}	148.9 ±18.4	4389.7 ±211.2c	195.1 ±4.3	27.7 ±0.2	11.6 ±0.8	24.4 ±1.9
25	I_{100}	269.1 ±54.9	3890.6 ±49.9d	191.8 ±4.2	34.4 ±0.1	15.4 ±1.7	22.4 ±2.6
	I_{50}	254.2 ±31.7	3823.7 ±6.6 d	189.3 ±0.8	34.4 ±0.1	14.4 ±0.4	18.3 ±1.2
	I_{25}	262.05 ±73.5	3842.2 ±19.3d	189.6 ±1.6	34.2 ±0.0	13.8 ±3.2	19.8 ±1.5
Ananas	I_{100}	144.7 ±14.2	3808.2 ±12.7d	185.5 ±0.9	34.7 ±0.1	11.9 ±0.1	23.1 ±1.2
	I_{50}	199.2 ±31.7	3824.5 ±10.8d	193.1 ±0.2	34.6 ±0.1	10.6 ±0.3	19.2 ±0.9
	I_{25}	154.80 ±48.3	3802.5 ±6.6d	185.3 ±1.4	34.8 ±0.0	13.8 ±1.0	22.9 ±0.2
CU-196	I_{100}	195.6 ±16.6	3794.8 ±13.2d	185.9 ±2.8	34.7 ±0.1	10.9 ±1.3	17.8 ±0.9
	I_{50}	208.2 ±19.0	3141.2 ±23.1e	168.2 ±2.7	38.4 ±0.4	10.7 ±0.9	20.0 ±1.6
	I_{25}	294 ±12.1	3083.5 ±112.2e	172.1 ±13.2	47.1 ±5.4	10.5 ±1.6	20.3 ±1.8
Mean							
Genotype-1		147.0 ±10.9c	4757.6 ±37.6a	215.9 ±3.7a	25.5 ±1.9c	9.9 ±0.7b	22.9 ±1.0a
Genotype-10		134.2 ±10.5c	4626.2 ±4.4b	200.7 ±0.6b	26.7 ±0.1c	10.9 ±.0.6b	21.9 ±1.1ab
Genotype-13		179.7 ±23.1bc	4329.8 ±113.7c	196.6 ±2.1bc	29.0 ±1.0c	11.1 ±0.6b	22.8 ±1.4a
Genotype-25		261.8 ±28.1a	3852.2 ±18.5d	190.2 ±1.4cd	34.3 ±0.0b	14.5 ±1.1a	20.1 ±1.1ab
Ananas		166.3 ±19.1c	3811.7 ±6.2d	188.0 ±1.4d	34.7 ±0.0b	12.1 ±0.5b	21.7 ±0.8ab
CU-196		232.6 ±17.5ab	3339.9 ±118.8e	175.4 ±4.8e	40.0 ±2.4a	10.7 ±0.7b	19.4 ±0.8b
Mean							
I_{100}		165.5 ±15.9	4270.9 ±108.9a	196.6 ±2.7	30.4 ±1.0	11.6 ±0.6	22.8 ±0.9a
I_{50}		203.1 ±14.2	4007.0 ±126.1c	194.8 ±4.2	31.1 ±1.5	11.4 ±0.5	19.5 ±0.5b
I_{25}		192.1 ±19.9	4080.7 ±142.9b	192.1 ±3.5	32.7 ±1.9	11.5 ±0.7	22.1 ±0.6a
$P^{Genotype}$		<.0001	<.0001	<.0001	<.0001	0.0014	0.0546
$P^{Irrigation}$		0.1313	<.0001	0.2097	0.1662	0.9556	0.0026
P^{GxI}		0.3890	<.0001	0.1239	0.0914	0.5163	0.2832

est gallic acid content (203.1 mg kg^{-1} FW). Genotype YYU-1 had the highest mean vanillic acid contents where significant differences occurred. For significant interactions, genotype YYU-1 had the highest vanillic acid content in the control group. Analyzing ferulic acid and quercetin contents, only the differences between genotypes were significant, and genotype YYU-1 had the highest ferulic acid contents and CU-196 had the highest quercetin contents. When analyzing the total phenolic content of the samples, no significant differences were found in water treatments and genotype × irrigation interactions. Only the average contents of total phenolic compounds obtained between genotypes showed significant differences, and YYU-25 was found to have the highest value. Genotypes YYU-1 and YYU-13 and I_{100} and I_{25} irrigation levels among the irrigation treatments were determined as producing the highest antioxidant contents (Tab. 5). Similar to this study, Seymen et al. [2021] reported that the level of change in the irrigation system did not affect the amount of total phenolic content in limited irrigation studies in which different plant materials were grafted on different watermelon rootstocks. In addition, the researchers stated that they obtained the highest value of antioxidant change in fruits after the application of full irrigation. In the present study, it was determined that I_{25} limited irrigation had a significant effect on antioxidant levels.

The significant genotype effects or genotype × treatment interactions observed in melon grown under water deficit conditions may be attributed to inherent differences in drought tolerance mechanisms among genotypes, such as variations in physiological traits, antioxidant enzyme activity, and proline accumulation, which influence how plants cope with reduced water availability. These genotypic variations could result in differential responses to irrigation regimes, affecting growth, yield, and fruit quality under stress conditions [Barzegar et al. 2018].

The genotype effects or genotype × treatment interactions in response to deficit irrigation stress can be explained by the distinct physiological and biochemical responses of different melon accessions. Variations in traits such as water use efficiency (WUE), total soluble solids (TSS), and yield under water-limited conditions highlight the genotypic adaptability to stress. For instance, Ivanaki exhibited higher drought tolerance, maintaining better WUE and yield compared to Khatooni, which suggests that genotype-specific mechanisms, such as osmotic adjustment or root system efficiency, play a key role in determining the plant's response to deficit irrigation [Taghadosinia et al. 2020].

In terms of the subject, material and method of the study, there are not many similar studies in the literature. In the present study, it was observed that the responses of the genotypes to salt and drought stress were different. It was determined that all eight genotypes gave different responses to both extreme conditions in terms of the parameters examined. Moreover, metabolic responses of the genotypes are also important, in addition to the growing conditions and stress levels.

Common responses of organic compounds under drought and salt stress

The four melon genotypes – YYU-1, YYU-4, YYU-10, and YYU-18 – exhibited notable variations in organic acid profiles when subjected to drought and salt stress. The stress conditions led to significant alterations in the concentrations of key organic acids, including malic, citric, oxalic, succinic, and fumaric acids.

In the salt stress experiment, all genotypes responded differently, but certain patterns emerged. Citric and malic acids were the most abundant organic acids detected, with citric acid generally recognized as the dominant organic acid in melons. Notably, YYU-4 demonstrated the highest concentrations of malic acid under control conditions. However, with increasing salt concentrations, the malic acid levels significantly decreased across genotypes, indicating a stress-induced response. The increases in oxalic acid concentrations, particularly in YYU-1 under higher salt doses, suggest a compensatory mechanism to counterbalance the effects of salt stress.

In contrast, fumaric acid levels remained consistently low, indicating that its accumulation is not significantly affected by salt stress. The findings align with previous research highlighting the adaptive role of citric acid in enhancing plant resilience to abiotic stressors, reinforcing the importance of this organic acid in stress responses.

Under drought conditions, similar trends were observed. Malic acid levels were highest in YYU-1, re-

flecting its superior adaptability under limited water availability. Interestingly, while citric acid levels did not show significant variation across irrigation treatments, YYU-13 recorded the highest citric acid content, further supporting its role in stress tolerance.

The results indicated that the succinic acid content increased significantly in YYU-10 under restricted irrigation. This response suggests that different genotypes might employ various strategies to cope with drought stress, emphasizing the complexity of organic acid regulation in response to environmental factors.

Overall, both salt and drought stresses influenced the organic acid profiles of the genotypes, with variations that underscore the role of specific organic acids in stress mitigation. These findings highlight the necessity for further research to elucidate the underlying mechanisms of organic acid accumulation and their roles in enhancing plant resilience under varying environmental conditions.

Common responses of phenolic compounds under drought and salt stress

The analyses reveal significant variations in phenolic compound responses among the four genotypes under both salt and drought stress conditions. Phenolics are known for their antioxidant properties, which mitigate the adverse effects of reactive oxygen species (ROS) generated during stress. The results indicate that while total phenolic content did not show significant differences across all genotypes and treatments, specific phenolic compounds such as gallic acid, vanillic acid, ferulic acid, and quercetin exhibited notable variations.

Under salt stress, significant interactions were observed for gallic and ferulic acids, particularly in YYU-4 and the Ananas cultivar, which suggests that these genotypes may have adapted specific metabolic pathways to cope with salinity. Similarly, the responses to drought stress highlighted that certain genotypes, like YYU-25, displayed higher levels of gallic acid, indicating a potential strategy for drought tolerance.

The findings align with previous studies suggesting that phenolic compound content can vary significantly with both salt and drought stress, influenced by genetic factors. For instance, while phenolic levels generally increased in response to salt stress in some studies (e.g. in broccoli and chilli [Zamljen et al. 2022, Haghighi et al. 2023]), the present study demonstrates a more complex interaction where genotype-specific responses are evident. The inherent physiological and biochemical mechanisms, including antioxidant enzyme activity and osmotic adjustment, appear to drive these differences across genotypes.

In conclusion, this research underscores the significance of understanding how different genotypes respond to abiotic stressors, as it can inform breeding programs aimed at enhancing stress resilience in melon varieties.

CONCLUSIONS

In this study, significant interactions occurred in organic acid and phenolic compound contents of genotypes exposed to drought and salt stress. At S_{50} and S_{75} salt levels, oxalic, citric and succinic acid contents were the highest in YYU-1 and YYU-4. Although there was an interaction with malic acid, a decrease was observed under stress conditions. There were no significant interactions for fumaric acid. At water limitation levels, significant interactions occurred at I_{25} level for oxalic, succinic and fumaric acid for YYU-1, YYU-10 and YYU-13 in terms of genotype × irrigation interaction. In addition, genotype YYU-1 was significant for the content of malic acid, and YYU-13 was significant for the citric acid content. Under salinity conditions, significant interactions were formed for phenolic compounds in terms of genotype × salinity. The total phenolic and antioxidant levels were significant among genotypes, particularly for YYU-4, cv. Ananas and CU-196. There were no significant interactions between phenolic contents in fruits and water limitation levels. It was concluded that it is worth noting that the capacities of the identified genotypes in saline and arid areas should be investigated with different parameters.

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DECLARATIONS

The corresponding author affirms that there is no conflict of interest related to this research study. The study was conducted with the sole objective of advancing scientific knowledge, and the authors declare no competing interests that might have influenced the outcomes or interpretations presented in this research.

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