Akademik Ziraat Dergisi 14(2): 144-155 (2025)
ISSN: 2147-6403 e-ISSN: 2618-5881 DOI: http://dx.doi.org/10.29278/azd.1816514

Araştırma
(Research)

Does Water Stress after Fruit Development in Melon Affect Fruit Quality and Nutrient Uptake?

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Alınış tarihi: 03 Kasım 2025, Kabul tarihi: 17 Aralık 2025
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Abstract

Objectives: In order to save irrigation water in melon cultivation, water stress was applied at different rates from fruit growth to harvest.

Materials and Methods: A total of six different experimental treatments were established including full irrigation applied throughout the season (control-I100) and five different water stress regimes (I80, I60, I40, I20, and I0) corresponding to 80 %, 60 %, 40 %, 20 %, and 0 % of water given to the S100 subject, respectively, during the fruit development stage until harvesting.

Results: As a result of the study, water stress caused significant changes in fruit quality as well as significant differences in nutrient element uptake. Water stress applied to melon caused a decrease in P and K uptake of approximately 25% and 20%, respectively. In addition, it provided an increase of 74%, 46%, 71% and 40% in Ca, Mg, Mn and B intakes, respectively, while it increased Fe intake by approximately 5.5 times. Increased water stress reduced the absorption of macronutrients from the soil, especially in melon, and also caused negative effects on fruit quality.

Conclusion: When the parameters examined in this study were evaluated together, no significant differences were found between I80 (20% water stress) application and I100 (full irrigation) subjects.

Keywords: *Cucumis melo* L., deficit irrigation, fruit colors, global climate change, plant nutrient element

Kavunda Meyve Gelişimi Sonrası Su Stresi Meyve Kalitesini ve Besin Alımını Etkiler mi?

Öz

Amaç: Kavun yetiştiriciliğinde sulama suyundan tasarruf etmek amacıyla, meyve büyümesinden hasada kadar farklı oranlarda su stresi uygulanmıştır.

Materyal ve Yöntemler: Sezon boyunca uygulanan tam sulama (kontrol-I100) ve meyve gelişimi aşamasından hasada kadar S100 konusuna verilen suyun sırasıyla %80, %60, %40, %20 ve %0'ına karşılık gelen beş farklı su stresi rejimi (I80, I60, I40, I20 ve I0) olmak üzere toplam altı farklı deneysel uygulama oluşturulmuştur.

Sonuçlar: Çalışma sonucunda, su stresi meyve kalitesinde önemli değişikliklere ve besin elementi alımında önemli farklılıklara neden olmuştur. Kavuna uygulanan su stresi, P ve K alınımında sırasıyla yaklaşık %25 ve %20 oranında bir azalmaya neden olmuştur. Ayrıca, Ca, Mg, Mn ve B alımlarında sırasıyla %74, %46, %71 ve %40'lık bir artış sağlarken, Fe alınımı yaklaşık 5,5 kat artmıştır. Artan su stresi, özellikle kavunda topraktan makro besin maddelerinin emilimini azaltmış ve meyve kalitesi üzerinde olumsuz etkilere neden olmuştur.

Sonuç: Bu çalışmada incelenen parametreler birlikte değerlendirildiğinde, I80 (%20 su stresi) uygulaması ile I100 (tam sulama) uygulamaları arasında anlamlı bir fark bulunmamıştır.

Anahtar Kelimeler: *Cucumis melo* L., kısıtlı sulama, meyve rengi, küresel iklim değişikliği, bitki besin elementi

Introduction

Melon (*Cucumis melo*) is an important vegetable species that is consumed by people during the summer months. Melon, which is easily grown in many regions of the world with hot climates, is known to have a total production of 28.5 million tons in an area of approximately 1062501 hectares. Turkey, considering its geographical and ecological structure, is the second largest melon producer country in the world after China, with a production of approximately 1.5 million tons, where melon is grown in almost every region (FAO, 2024). The most important reason why melon is preferred by people is its high flavor and aroma, and the bioactive substances taken from the flesh of the fruit provide important contributions to human health. It is known that the sugar content in melon varies according to the variety and varieties, as well as the ecological factors and applications in which it is grown cause significant changes. For example, it has been stated that a Kırkağaç type winter melon variety contains approximately 9-12% sugar at different water stress levels (Ercan et al., 2023).

There are different parameters such as sugar acids, acidity, aroma, color, and flesh hardness in melon, which are the reasons why it is preferred by people and reveal the quality of the fruit flesh. In addition to sugar components such as glucose, fructose and sucrose, which contribute to the flavor of melon, it has been reported that organic acids and some amino acids also contribute (Ercan et al., 2023). For this reason, in addition to yield, the flavor and quality of the fruit flesh, which is important in melon, vary with many factors and are among the topics researched by researchers (Ercan et al., 2023).

Vegetable species generally require high irrigation water. If high yield and fruit quality are targeted in melon, irrigation is a must during sensitive growth periods (Hartz, 1997). In large areas and in production systems where modern production techniques are applied, it is a priority to determine water-yield relationships well. While excessive irrigation restricts plant growth, causes disease formation and fruit damage, insufficient irrigation water leads to yield losses and significant restrictions on fruit quality. There are many studies that show different effects of the amount of irrigation water applied on yield and fruit quality (Ercan et al., 2023; Zapata-García et al., 2025). It has been reported that exposure of melon plants to water stress during or before the harvest period causes negative effects on soluble solids contents (SSC), shrinkage of fruits (Fabeiro et al., 2002), and decrease in yield (Yavuz et al., 2021). It has been reported that melon is generally negatively affected by water deficit and that fruit set and flowering periods are very sensitive to water deficiency (Fabeiro et al., 2002).

Plants need not only macronutrients such as N, P and K, but also some micronutrients that play an important role in metabolic processes. Water deficiency in the rhizosphere not only reduces water uptake in plants, but also causes significant restrictions in nutrient uptake. Accordingly, water deficit reduces photosynthesis rate, disrupts enzyme and metabolic activities, oxidative stress in plant cells increases and the balance in nutrient absorption is disrupted (Cheraghi et al., 2023). Inadequate nutrition in plants causes many negative effects such as yellowing of leaves, shrinkage in vegetative parts, shrinkage in fruits, regression in coloration and loss of aroma. For this reason, it is important to develop approaches that will protect plants' nutrient uptake from the soil.

Drought, which occurs in many parts of the world because of global climate change, causes atmospheric evaporation losses. It is observed that many plant species are exposed to drought, which restricts plant growth as well as yield and quality losses (Seymen et al., 2024). Many factors such as the time of drought, its severity and duration are important for plants, and plant species and varieties also respond differently. However, drought, which is increasing its effect day by day, causes significant quality losses in melon as in many species. For this reason, researchers are conducting research on the most economical use of existing water resources against the limited availability of water resources. When the studies conducted on melon are examined, determination of tolerant genotypes, water limitation and period studies come to the fore (Yavuz et al., 2021; Seymen et al., 2024). Melon cultivation, especially in semiarid regions and open field conditions, is exposed to water stress.

For this reason, determining the effects on plant nutrient uptake and fruit quality traits is among the important issues when determining appropriate irrigation strategies in today's conditions, and it has been seen in the literature reviews that there is a significant deficiency in this regard. It has been seen that the effects of water restriction on nutrient uptake and fruit quality, especially in melon, from fruit development to harvest, have not been investigated sufficiently. The aim of the current study was to determine the effects of different water restriction levels applied from fruit development to harvest on nutrient element uptake and fruit quality.

Materials and Methods

Experimental Area, Plant Materials, and Experimental Design

The experiment was carried out in the experiment field of the Faculty of Agriculture, Selçuk University, Konya, Turkey (38°05′N, 32°36′E, with an altitude of 1006 m). The experiment was carried out during the vegetation period in 2024, and some records were taken with the meteorological station located in the experimental field. Accordingly, it was observed that the relative humidity values in the experimental field varied between 25.5% and 81.0% (avg. 49.0%), the total precipitation during the period varied between 66.2 mm and the temperatures varied between 6.5 and 36.8 ^{o}C (avg. 23.3 ^{o}C). Physical and chemical analyzes were made on soil samples taken from different layers of the experimental field (Table 1). It was observed that the soil, whose field capacity was between 39.2 and 42.3%, was poor in organic matter and good in terms of nutrients. .

Table 1 Some physical and chemical properties of the soil of the experimental field

Soil depth (cm)	pH	Organic Matter (%)	Texture	Bulk density (g cm^{-3})	Field capacity (*FC*)		Wilting point (*WP*)		Total available water *(TAW)*	
					m^{3}m^{-3}	mm	m^{3}m^{-3}	mm	m^{3}m^{-3}	mm
0-30	7.53	2.10	C-L	1.32	0.394	118.2	0.227	68.1	0.167	50.1
30-60	7.58	1.37	C-L	1.34	0.398	119.4	0.253	75.9	0.145	43.5
60-90	7.55	1.42	C-L	1.26	0.423	126.9	0.263	78.9	0.160	48.0
Total (0-90 cm)										141.6

	N (ppm)	P (ppm)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	B (ppm)
0-30	28.11	9.67	7216	874	462	135	1.73	4.11	12.95	0.73	0.91
30-60	23.75	3.65	7432	444	432	162	1.75	5.23	11.33	0.33	0.97
60-90	38.42	5.17	7543	386	474	133	1.97	5.62	10.43	0.45	0.13

C-L: Clay loam

Sürmeli F1 melon variety, which is commercially grown and is suitable for cultivation under open field conditions and has a strong aroma was chosen as plant material. All experimental subjects were fully irrigated until fruit formation. During the fruit formation period until harvest, 6 experimental treatments were established, including full irrigation (control) (I100) and 5 different deficit irrigation regimes, which received 80 % (I80), 60 % (I60), 40 % (I40), 20 % (I20), and 0 % (I0) of the water given to the full irrigation subjects. These treatments were arranged in a randomized block design, with three replications. Each plot was 5 m in length and consisted of a total of 20 plants in 4 rows with the inter- and intra-row spacing combination of 2x1 m.

Seed Sowing and Irrigation

Seed sowing 2 seeds were sown in the holes opened on May 23, 2024. Immediately after seed sowing, irrigation was applied equally to all plots. Equal amounts of irrigation water were applied to all trial subjects until the irrigation program included restricted irrigation. Restricted irrigation applications started on July 23, 2024, and irrigation water was applied to all trial plots except I0 a total of six times with seven-day intervals. To calculate the amount of irrigation water applied to treatment and control subjects within the plots using the standard FAO-56 method (Allen et al., 1998). Irrigation amounts applied to irrigation issues and calculated evapotranspiration values are shown in Table 2.

Table 2 Total amounts of irrigation water, effective rainfall, ΔS, and ETa for melon

Treatments	Irrigation depth (mm)	Rainfall (mm)	ΔS (mm)	ETa (mm)
I100	430.5	66.2	12.6	509.3
I80	376.3	66.2	20.9	463.4
I60	322.1	66.2	28.6	416.9
I40	267.8	66.2	37.8	371.8
I20	213.6	66.2	40.2	320.0
I0	159.4	66.2	78.0	303.6

Determination of Fruit Rind Thickness, Fruit Flesh Thickness, pH and SSC

After cutting the melon fruits that reached harvest maturity, the fruit rind thickness was determined by measuring the distance between the fruit flesh and the outer shell with a caliper. Fruit flesh thickness measurements were also made from the same area. Then, the pH values of the fruit juice were determined with a pH meter in the samples from which the fruit juices were extracted. SSC values were determined with a refractometer device in the same fruit juices.

Determination of fruit rind and flesh color

When the fruits reached harvest maturity, fruit colors were determined in terms of L, a, b from 5 fruits in each plot using the color determination device (Chroma Meter CR-400) based on the dominant color of the fruit. After the same fruits were cut, color measurements were made from the fruit flesh.

Analysis of Nutrient Elements

Leaf samples taken from the sixth or seventh leaf of the plots in the fully irrigated and water-limited applications were first dried in the shade, then in an air-circulated drying cabinet at 70 ^oC until they reached constant weight and then ground. 0.2 g of the dried and ground samples were weighed and dissolved with 5 ml of HNO_3 under high temperature (210 ^oC) and high pressure (200 PSI) in a microwave device (CEM Mars 5). Then, the samples were transferred to a 25 ml volumetric flask, cooled, and made up to the desired temperature with deionized water. These filtrates were immediately filtered with Whatman 42 filter paper and transferred to 25 ml polyethylene bottles, and the plant nutrients in the filtrate were determined with a 5110 ICP-OES (Inductively Coupled Plasma Optic Emission Spectrometer) (Agilent) device (Skujins, 1998).

Sugar Profile

To examine the sugar profile, 0.6 g of melon fruit was extracted with a homogenizer (wisemix™ HG-150 DAIHAN Scientific, Korea) in 3 mL of ultrapure water. Then, the obtained homogenate was centrifuged at 4500 rpm for 15 min (NF 800; Nuva, Turkey). The supernatant was filtered and analyzed with an Agilent 1260 Infinity Series high-pressure liquid chromatography (HPLC) system equipped with an interactive index detector.

Data Evaluation

The measurements taken to reveal the effects of limited irrigation applications applied after fruit development on fruit quality and nutrient elements in leaves were subjected to statistical analysis with JMP-13 package program. Principal component analysis (PCA) was performed in the same statistical software to find important parameters and evaluate their effects together.

Results

Effects of deficit irrigation on fruit rind thickness, fruit flesh thickness, pH and SSC

It was observed that water stress caused significant decreases in fruit rind thickness in melon. The highest fruit rind thickness was obtained from full irrigation application (I100) as 15.69 mm, while it decreased as stress increased and the lowest fruit rind thickness was obtained from I0 application where the highest stress was 11.14 mm. When fruit flesh thickness was examined, there was no decrease up to 60% water restriction application, while significant losses were observed in subjects where 80% water restriction (I20) and full stress (I0) were applied. Water restriction applied after fruit development in melon had no statistical effect on pH. In addition, when SSC values were examined, although a decrease was observed in 20% water restriction application, SSC values of other applications were statistically in the same group (Figure 1).

Effects of Deficit Irrigation on Fruit Rind and Flesh Color

It was observed that water restriction applied to melon had statistically significant effects on fruit rind and flesh color. While water restriction applications did not show a significant effect on fruit rind color L* and a* values, significant changes were observed in b* values. While the lowest b* value was obtained from the fully irrigated subject, an increase in b* value occurred as water stress increased. When fruit flesh color was examined, it was seen that the applied water restriction caused significant changes. While the lowest L* value was obtained from the I80 application where 20% water restriction was applied, increases were observed in L* value as water stress increased. When fruit flesh color a* values were examined, the highest values were obtained from the subjects where full irrigation or light water stress was applied, while lower a* values were obtained in applications where water stress was severe. Fruit flesh color b* value was similar to L* value, the highest values were obtained from the applications where stress was most severe (Figure 2).

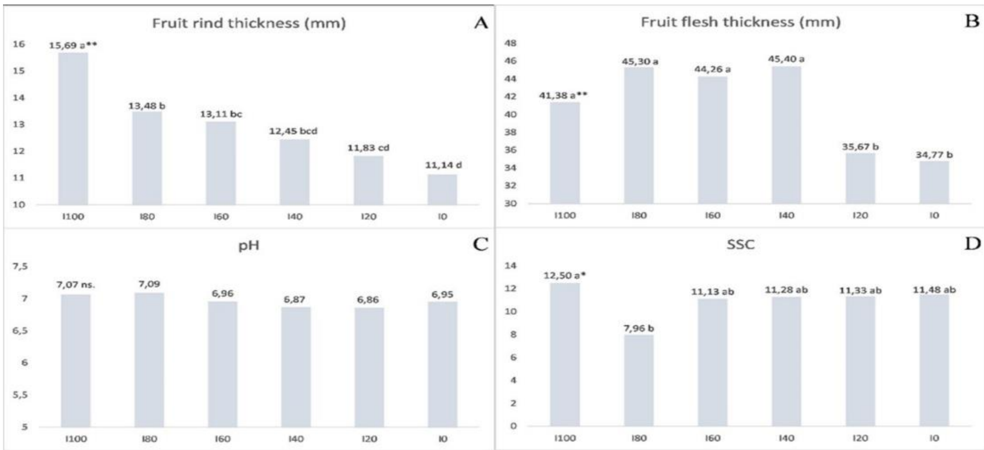

Figure 1. Effect of deficit irrigation applied between fruit development and harvest on fruit rind thickness, fruit flesh thickness, pH and SSC (brix) in melon. Analyses were made in JMP-13 statistical program according to 5% (*) and 1% (**).

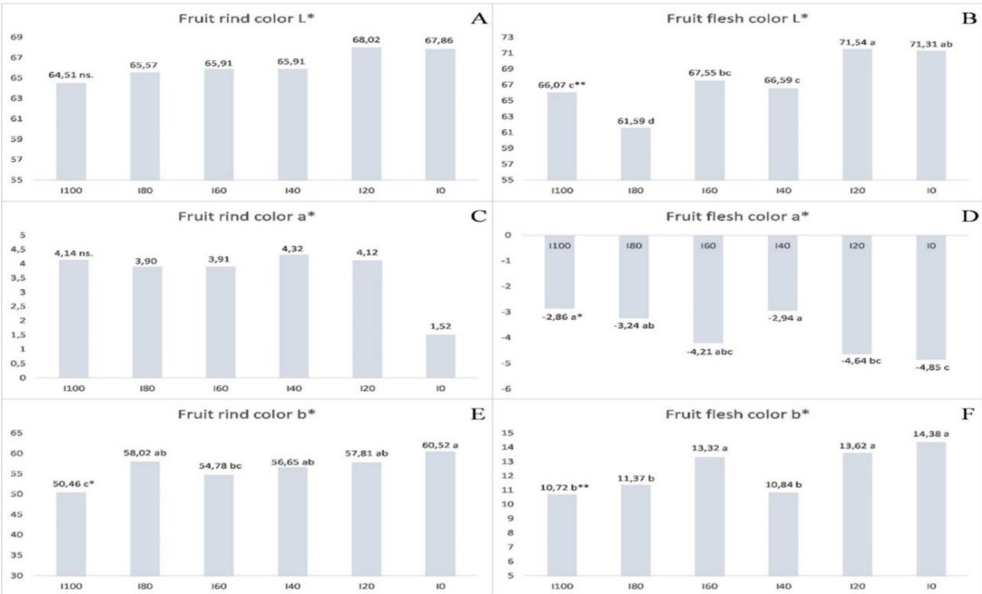

Figure 2. Effect of deficit irrigation applied between fruit development and harvest on fruit rind and flesh color in melon.

Effects of Deficit Irrigation on Macro Plant Nutrient Uptake

After fruit development in melon, different irrigation levels applied affected macro plant nutrient uptake. While the highest P content was obtained from I60 application with 3286 ppm, the lowest P content was obtained from 120 applications with 2405 ppm. While P content increased from full irrigation to 40% water stress application, water stress applied after this level revealed a significant decrease in P content. A similar situation was observed in K content. Similarly, the highest K content was obtained from I60 application, while the lowest K content was obtained from I20 application. Unlike these, Ca content was obtained at the lowest levels from full irrigation and 20% water restriction (I80) applications, and significant increases occurred in Ca content as stress increased. Similarly, while the lowest Mg content was obtained from full irrigation with 4906 ppm, significant increases occurred in Mg content as stress increased. When S content was examined, it followed an up-and-down course according to irrigation levels. While the highest S content was obtained from the I20 application, the lowest S content was obtained from the I80 application (Figure 3).

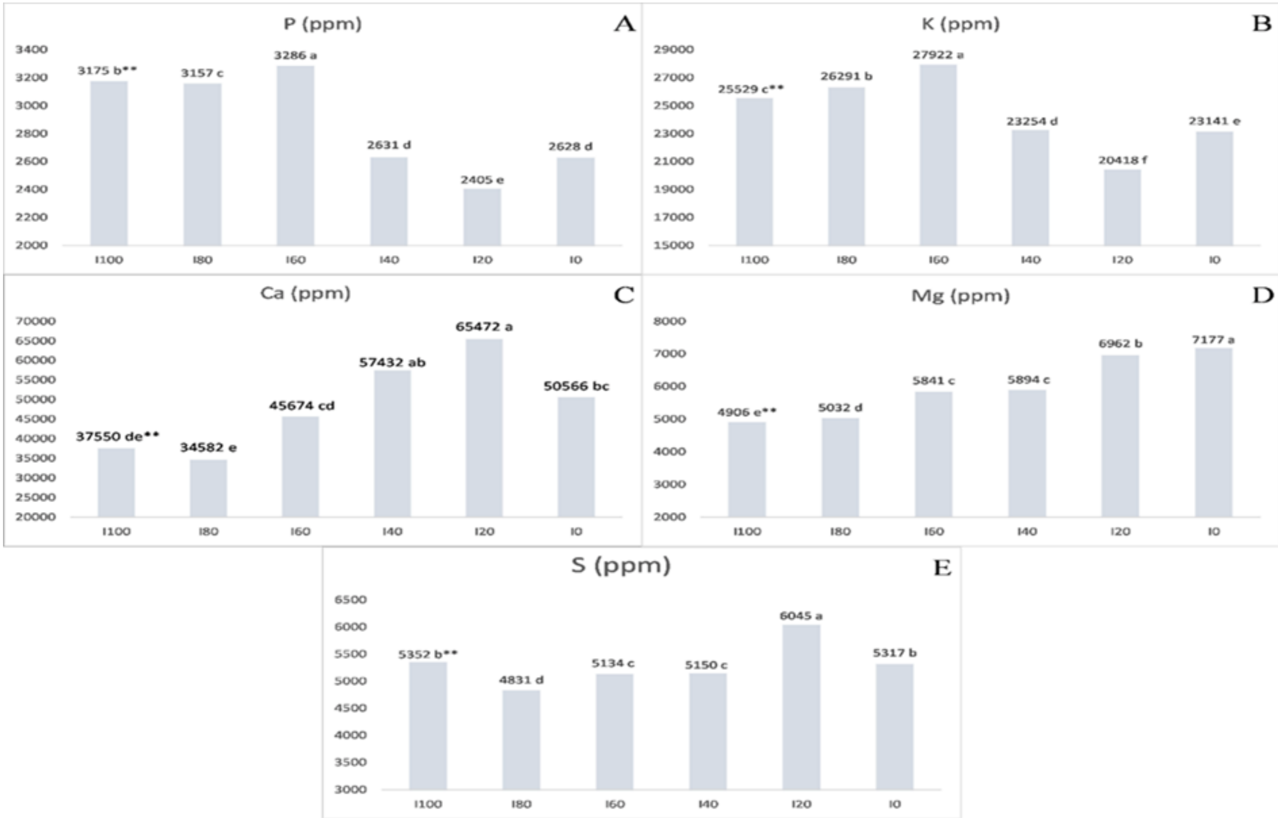

Figure 3. Effect of deficit irrigation applied between fruit development and harvest on major plant nutrient uptake in melon.

Effects of Deficit Irrigation on Micro Plant Nutrient Uptake

Different irrigation levels applied to melon revealed statistically significant differences in micro plant nutrient uptake. When Fe content was examined, it was seen that there was serious Fe accumulation in severe water stress. Full irrigation and I60 applications were the applications with the lowest Fe contents with 173 and 197 ppm Fe contents, respectively. In the I0 application where the highest stress was applied, an approximately 5.5-fold increase of 964 ppm Fe content was obtained.

Similarly, the lowest Mn content was obtained from the full irrigation application, 32.25 ppm. As water stress increased, Mn uptake increased and the highest Mn content was obtained from the I0 application where water stress was highest, with 55.19 ppm. The highest Cu and Zn contents were obtained from the I60 application, while the other applications had values close to each other. While the lowest B content was obtained from full irrigation and I20 applications, the highest B content was obtained from the I0 application (Figure 4).

Effects of Deficit Irrigation on Sugar Profile

Water stress in melon caused changes in the sugar profile. The highest glucose content was obtained from I80 application with 2.03%, followed by full irrigation with 1.94%. As water stress increased, glucose content decreased and the lowest content was obtained from I0 application with the highest stress, 1.56%. Similarly, when looking at fructose content, the highest content was obtained from I80 application with 2.14%, followed by full irrigation with 2.01%. The lowest fructose content was obtained from I0 and I20 applications, which were exposed to the most severe stress.

When looking at sucrose content, the highest content was obtained from I20 application with 4.16%, while the lowest value was obtained from I80 application with 2.59%. When looking at total sugar, the highest content was obtained from full irrigation with 7.74%, while the lowest content was obtained from I80 application with 6.79% (Figure 5).

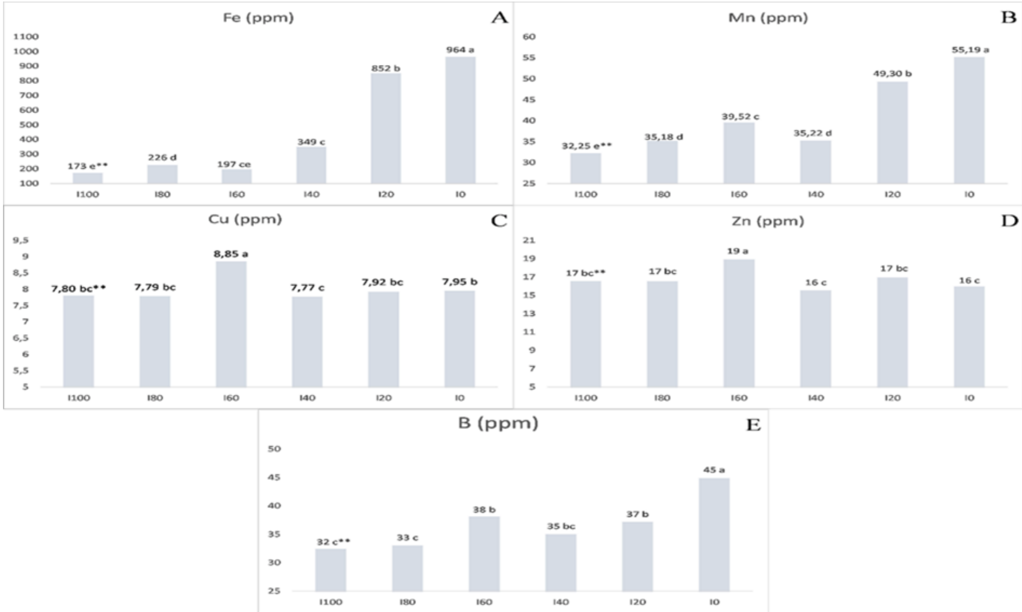

Figure 4. Effect of deficit irrigation applied between fruit development and harvest on minor plant nutrient uptake in melon.

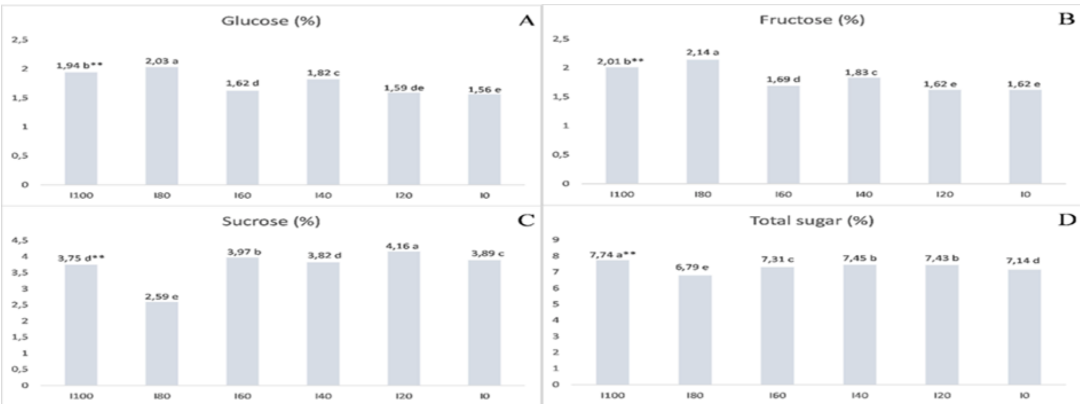

Figure 5. Effect of deficit irrigation applied between fruit development and harvest on sugar content in melon.

Principal Component Analysis (PCA)

In order to interpret the water limitation and important parameters in melon, all parameters were subjected to PCA (Table 3). As a result of PCA, it was seen that the study was explained by 96.13% in four components. The first component, which was explained most strongly, was explained by 57.53%, and FRCL*, FFCL*, FRCb*, Ca, Mg, Fe, Mn, and B were the strongest positively explaining parameters. FRD, FFT, FFCa*, P, Gl, and Fr were the strongest negatively explaining parameters. The second component explained the study by 17.22%, and SSC, FRCa*, S, Su, and TS were the strongest positively explaining parameters, and FRCb* was the strongest negatively explaining parameters. When the biplot graph drawn from the two most important components was examined, the relationships between the parameters and water limitation applications emerged (Figure 6). When the figure was examined, it was seen that the first component clearly explained the water levels. In the positive region of the first component, there are severe water stress subjects, while in the negative region, there are full irrigation subject and 20% water restriction (I80) subject. Other applications are in the middle regions. In severe irrigation conditions (I0 and I20), L* values from fruit colors and b* values from fruit flesh colors, Ca, Mg and S from macro nutrients, Fe, Mn and B from micro nutrients have been the parameters that give and explain important results.

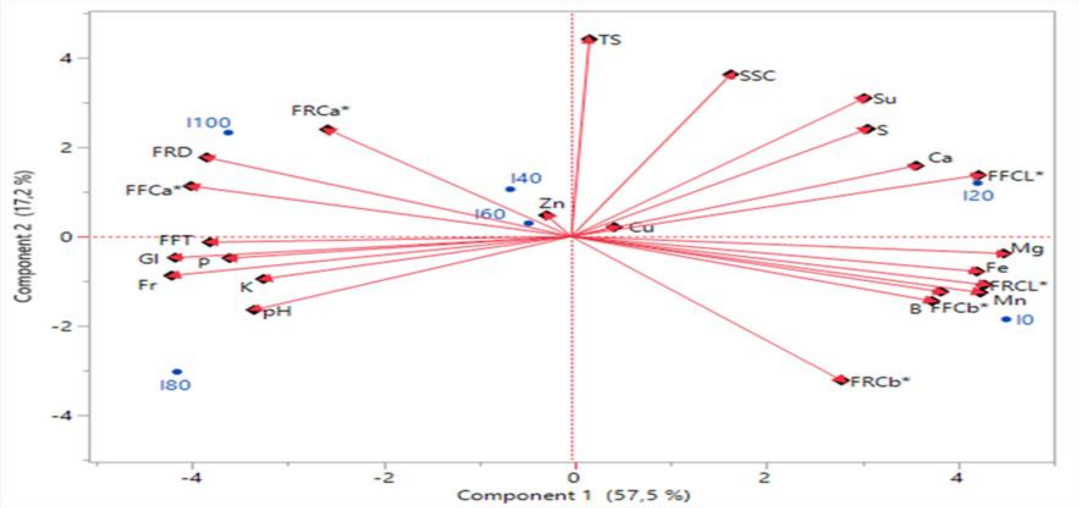

Figure 6. Score-loading biplot graph created using component 1 and Component 2.

Table 3 Principal component analysis (PCA) of the average parameters obtained from deficit irrigation applied between fruit development and harvest in melon

Items	PC1	PC2	PC3	PC4
Eigenvalue	13.81	4.13	3.47	1.65
Percentage of variance	57.53	17.22	14.46	6.88
Cumulative variance	57.53	74.75	89.25	96.13
Eigenvectors				
FRD	-0.225	0.191	0.052	0.247
FFT	-0.223	-0.013	0.054	-0.361
pH	-0.196	-0.178	0.071	0.398
SSC	0.098	0.393	0.070	0.298
FRCL*	0.255	-0.116	-0.051	-0.090
FRCa*	-0.150	0.259	-0.061	-0.439
FRCb*	0.167	-0.348	-0.124	-0.171
FFCL*	0.252	0.148	0.053	0.112
FFCa*	-0.235	0.122	-0.190	-0.027
FFCb*	0.228	-0.133	0.225	0.046
P	-0.211	-0.052	0.316	0.118
K	-0.190	-0.102	0.350	0.038
Ca	0.213	0.171	-0.137	-0.332
Mg	0.267	-0.040	-0.011	-0.032
S	0.183	0.261	-0.087	0.014
Fe	0.250	-0.084	-0.132	0.136
Mn	0.253	-0.135	0.030	0.133
Cu	0.026	0.022	0.512	-0.206
Zn	-0.015	0.051	0.483	-0.198
B	0.223	-0.156	0.150	0.174
Gl	-0.245	-0.051	-0.207	0.053
Fr	-0.247	-0.094	-0.160	0.090
Su	0.181	0.335	0.126	0.015
TS	0.011	0.47835	-0.004	0.163

: The statistical significance of the means of two different treatments subjected to PCA performed using the JMP-13 software program was evaluated at the two significance levels of 0.05 ($P<0.05$) and 0.01 ($P<0.01$). FRD: fruit rind thickness (mm), FFT: fruit flesh thickness (mm), SSC: soluble solids contents, FRCL: fruit rind color L*, FRCa*: fruit rind color a*, FRCb*: fruit rind color b*, FFCL*: fruit flesh color L*, FFCa*: fruit flesh color a*, FFCb*: fruit flesh color b*, P: phosphorus content, K: potassium content, Ca: calcium content, Mg: magnesium content, S: sulfur content, Fe: iron content, Mn: manganese content, Cu: copper content, Zn: zinc content, B: boron content, Gl: glucose (%), Fr: fructose (%), Su: sucrose (%), TS: total sugar (%).

Discussion

Drought tolerance in plants is a challenging task for breeders. There is limited research to identify the basic agronomic physiological traits for the identification and improvement of drought tolerant genotypes. This is because most of the drought adaptive and structural traits are controlled by polygenic epistatic and labile QTL, which are greatly affected by genotype-environment interactions (Mwadzingeni et al., 2017). In addition, identifying genes associated with drought stress tolerance and their expression and bridging the gap between theoretical research and applied crop breeding is another challenge for introduced tolerance breeding (Luo et al., 2019). Therefore, useful experiments should be established to demonstrate agronomic, physiological and biochemical changes of genotypes under stress conditions in order to identify drought tolerant genotypes and use them in breeding (Sallam et al., 2019). Indeed, although gene expressions are determined in determining the effects of drought stress in melon, it is known that agronomic, physiological and biochemical changes reveal important results (Yavuz et al., 2021). In our study, it was observed that water restrictions applied after fruit development in melon caused significant changes in fruit characteristics and nutrient uptake.

When plants are exposed to water stress, they reduce their vegetative parts to avoid stress, and this results in the shrinkage of fruits, causing yield and quality losses. In fact, in a study conducted on melon, water restriction caused a significant decrease in fruit rind thickness and fruit flesh thickness (Hamdan et al., 2017). Similarly, it has been reported that fruit rind thickness decreases as water restriction increases in watermelon (Yavuz et al., 2020). Water stress applied at different developmental stages has been reported to have significant effects on SSC in melon. SSC between 10.9 and 13.3 was achieved across treatments, and SSC was reported to increase under stress conditions (Yavuz et al., 2021). In addition, SSC between 10.2-10.8 brix was obtained in different irrigation strategies applied to watermelon, and it was reported that different irrigation levels did not have positive effects on SSC (Yavuz et al., 2025). It has been observed that water restriction applications applied after fruit development in melon caused a decrease of 29% and 23% in fruit rind thickness and fruit flesh thickness, respectively. Although SSC values were observed to decrease at 20% water restriction, no statistically significant change was observed in other water restriction applications.

Color changes in plants and fruits under drought stress conditions are among the important approaches in determining the effects of stress. For this reason, L*, a*, b* values measured in fruits reveal significant differences under stress conditions. The L* value varies between 0 and 100 and explains the coloration between black and white. Positive values in the a* value determine the red-purple tone, while negative values define bluish-green colors. In b* values, positive values indicate yellow, and negative values indicate blue (McGuire, 1992). Portela and Cantwell, (1998), reported that the L* value of melons varied between 63.7–66.8. Silva et al., (2016) found that the L* values of melon varied between 53.5–77.38. In another study, Falah et al., (2015) reported a* and b* values as 8.37 and 32.13, respectively. Ercan et al., (2023) reported that L* values were between 65.7-71.7, a* values were between 2.5-2.7 and b* values were between 10.7-13.7 in Kırkağaç type melons under full irrigation and stress conditions. Different researchers reported that many conditions such as genetic structure, growing conditions and ripening period have significant effects on fruit colors (Itle and Kabelka, 2009). In our results, water stress made the biggest difference in b* value, and it was revealed that as water stress increased, more yellowness occurred in the fruit peel color. In the fruit flesh, while the brightness increased, it was revealed that yellowness increased.

There is an important relationship between the amount of water available and the absorption of nutrients from the soil by plants. When plants take in water through their roots, nutrient uptake also occurs. Therefore, a decrease in the amount of soil water results in a decrease in the uptake of nutrient elements by plants. This situation occurs because of various factors such as decreased ion diffusion in the soil, disruptions in nutrient uptake and transport kinetics from the roots (Bista et al., 2018), and prevention of mass flow because of mineralization. The decline in photosynthesis and assimilation resulting from water stress limits the need for energy, and this negatively affects plant development and causes a decrease in vegetative parts (Taheri et al., 2021). In fact, it has been observed that the water restriction we applied to melon caused a decrease of up to 25% in P uptake and 20% in K uptake. While P has an important role in the storage and transfer of energy, photosynthesis mechanism, transportation of carbohydrates and regulation of structural enzymes, K prevents stress damage by regulating turgor pressure and reducing transpiration under drought stress conditions (Andersen et al., 1992).

It has been reported that calcium has a complex structure and plays a role in many signaling systems in plants under drought stress conditions. For this reason, Ca is an important nutrient element that increases tolerance to many stress conditions (Nayyar and Kaushal, 2002). It has been observed that water restriction applied after fruit development in melon causes Ca accumulation. High Ca content has been seen as a defense mechanism against the effects of stress. Mg plays a role in important activities such as chlorophyll synthesis, enzyme activation, and membrane stability in plants. In addition, it contributes to many physiological and biochemical processes affecting plant growth and development (Verbruggen and Hermans, 2013). Mg content in melon also increased by up to 46% compared to water restriction levels and has been an important factor in protecting plants from stress.

Fe deficiency resulting from drought causes a decrease in chlorophyll levels and consequently chlorosis in leaves (Ahanger et al., 2016). In soils with high water content, the Fe^{2+}/Fe^{3+} ratio is higher and, in this case, plants can more easily absorb iron from the soil. However, this ratio decreases in arid soils and high levels of O_2 cause Fe^{3+} to be less soluble than Fe^{2+}, limiting Fe uptake (Sardans et al., 2008). However, our study revealed that Fe uptake increased approximately 5.5 times under stress conditions. Similarly, a study conducted on lettuce reported that drought stress caused a significant increase in Fe uptake (Yavuz et al., 2023). In stress conditions, plants respond with organic acid accumulation and release to avoid negative effects. As a result of organic acid release, the soil rhizosphere becomes acidified, Fe solubility increases, and uptake by the roots becomes easier, and Fe mobility increases within the plant (Ahanger et al., 2016). When the results obtained are examined, it is observed that the melon plant activates a similar mechanism to protect itself from water stress and increases Fe uptake. High levels of iron have toxic effects on plants. Excessive iron accumulation can lead to damage to plant cell membranes, reducing growth, yield and general health. It has been observed that similar results occur in melon with stress. Mn plays an important role in photosynthetic activity under stress conditions, and plays an important role in balancing chlorophyll concentration and superoxide dismutase activity. It acts as a scavenger of harmful superoxide and hydrogen peroxide radicals formed in plants (Millaleo et al., 2010). In fact, in our study, an increase of approximately 71% was observed in Mn content under water stress conditions. This situation was seen as an important mechanism in increasing tolerance to stress.

Many studies have reported that there is a strong relationship between water restriction and sugar content, and that the amount of sugar increases as drought increases (Seymen et al., 2021). Appropriately controlled water restriction is one of the methods applied to improve the sugar content in watermelon and melon (Kyriacou et al., 2018). When the sugar ratios we obtained were examined, it was seen that the sucrose content increased under water restriction conditions.

PCA is a statistical method used in stress-related studies to identify the important parameters and interpret the effects of different applications. It can also reveal significant changes in response to stress conditions. Many researchers have used it to determine the effects of abiotic stress on plants (Seymen et al., 2024; Yavuz et al., 2025; Dolu et al., 2025). The results of PCA in our study indicated the major variance in data (57.53 %) explained by the first component (PC1) and thus its strong dominance as the most important component determining water stress. Various studies have emphasized that water stress is an important factor, as revealed by PCA analysis, and it is related to variables explained by PC1 in a high proportion (Seymen et al., 2024; Yavuz et al., 2025a). Among the water deficit regimes applied to melon plants after the fruit development period, I100 and I80 gave the best results in terms of RRCa*, FFCa*, FRD, FFT, Gl, Fr, P and K and thus were considered the most important and effective treatments. The obtained results indicated that the application of 20 % water deficit to melon after fruit development is safe.

Conclusion

In melon, restricted irrigation applications applied after the fruit development period cause changes in fruit color as well as reducing fruit peel and flesh thickness. While water stress significantly limits the uptake of nutrients P and K, it has shown significant increases in Ca, Mg, Fe, Mn and B uptake. In addition, significant decreases were observed in glucose and fructose sugars under water stress conditions, and there were significant sugars that changed under stress conditions. It has been observed that 20% water restriction to be applied after fruit development has similar results with full irrigation in terms of fruit quality and nutrient uptake and is applicable in agricultural cultivation. Considering the increasing difficulty of accessing irrigation water in agricultural lands with semiarid climates; it has been concluded that 20% water stress to be applied in melon from fruit development to harvest is a very important application in terms of protection and sustainability of water resources.

Author Contributions

All authors contributed to the conception and design of the study. M.S., D.Y., and M.P. designed the study and wrote and edited the article. R.N.Ö and D.M. established the field trial and performed laboratory analysis. All authors have read and approved the final version of the manuscript.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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