Turkish Journal of Agriculture - Food Science and Technology, 12(s1): 2089-2096, 2024
DOI: https://doi.org/10.24925/turjaf.v12is1.2089-2096.7088

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Evaluation of Physiological Changes in Important Dried Apricot Varieties Under Drought Stress

Handan Ölmez[1,a,*], Belgin Çelik[2,b], Adalet Mısırlı[3,c]

[1]*Olive Research Institute, Bornova, 35100, Izmir, Türkiye*
[2]*Apricot Research Institute, Yesilyurt, 44090, Malatya, Türkiye*
[3]*Ege University, Faculty of Agriculture, Department of Horticulture, 35100, Izmir, Türkiye*
[*]*Corresponding author*

ARTICLE INFO

Research Article

Received : 22.08.2024
Accepted : 06.09.2024

Keywords:
Apricot
Drought stress
Physiological changes
Resistance
Climate change

ABSTRACT

Nearly all of the apricot varieties grown in Malatya are dried apricots and the plantation areas in this region are expanding daily. Due to the impact of climate change, producers are growing apricots mostly under limited irrigation or even dry conditions. Therefore, it is essential to determine the drought resistance characteristics of the varieties commonly cultivated in this region. In this study, different irrigation levels of 100%, 75%, 50% and 25% of available water were applied to Hacıhalioğlu, Kabaaşı, Çataloğlu, Hasanbey and Soğancı apricot varieties. To evaluate the resistance of the varieties to drought stress and its relationship with physiological changes, chlorophyll a and b, carotenoids, total sugar, total starch and abscisic acid contents in the leaves were analyzed. A decrease in chlorophyll a and b, carotenoids, total starch values and an increase in total sugar and ABA values were determined due to the decrease in irrigation rates. In Kabaasi and Hasanbey varieties, which were observed as the most resistant to water shortage, chlorophyll a and b, carotenoids, total starch values were higher and total sugar content was lower at decreased irrigation levels. No difference was detected between varieties in ABA values. As a result of the observations in the drought resistance tests and physiological analyses, it was concluded that the most resistant varieties were Kabaasi and Hasanbey. Unfortunately, the most sensitive variety was the most widespread Hacihaliloglu. In addition, analyzing and evaluating the physiological changes occurring in apricot under drought stress will be useful in developing the most appropriate irrigation strategies for each variety and increasing water use efficiency. It may also be useful in cross-breeding studies to develop new drought-resistant varieties.

[a] olmezata@hotmail.com https://orcid.org/0000-0003-4577-8804
[b] belgin.celik@tarimorman.gov.tr https://orcid.org/0000-0003-1104-5530
[c] adalet.misirli@ege.edu.tr https://orcid.org/0000-0002-6128-9974

Introduction

Malatya province in Turkiye is the global leader in dried apricot production and export. Approximately 90-95% of the apricots grown in Malatya are dried and exported. 2022, the province exported 76.4 thousand tons of dried apricots, generating $402 million in revenue (Hasdemir, 2023).

The interest in dried apricot cultivation in the Malatya region is constantly increasing yearly; more and more areas are being planted each year. This situation causes irrigation problems, especially in years when summers are dry. In recent years, producers have been trying to cultivate with little or no irrigation due to limited water resources.

Drought stress is becoming increasingly important in plant cultivation. Plants are affected by drought depending on species, age, growth stage and development period, drought level and duration, and environmental factors. They have developed different morphological, physiological and biochemical responses to avoid or overcome stress (Ghahremani et al., 2023; Liu et al., 2023). Especially, when vegetative development accelerates, regular limited water applications to trees are recommended. Thus, the efficiency of using of existing water resources will increase along with the increase in yield (Chalmers et al., 1986; Mitchell et al., 1989).

Physiological parameters such as chlorophyll, carotenoid, total sugar, total starch and abscisic acid content play an important role in resistance to drought stress. Chlorophyll content is affected by drought stress and decreases significantly compared to normal irrigation conditions (Aghanejad et al., 2015). In contrast, carotenoid levels are increased due to drought and ROS is neutralized to reduce cellular damage (Niyogi, 1999; Fang & Xiong, 2015). Carbohydrate metabolism is also affected under drought stress conditions. Concentrations of sugars such as fructose and glucose change. This change is effective in photosynthetic metabolism. It is stated that sugar molecules activate the antioxidant defense mechanism

(Keunen et al., 2013). Drought is also a factor affecting starch content (Bing et al., 2014). On the other hand, it is known that water shortage perceived by the roots is transmitted to the stem by abscisic acid (ABA). It has been determined that ABA ensures the closure of stomata in drought stress and enables it to resist adverse conditions (Anjum et al., 2011).

In this study, it was aimed to determine and compare the drought resistance of the most essential dried apricot varieties such as Hacihaliloglu, Cataloglu, Hasanbey, Kabaasi and Soganci, by examining the physiological changes in their leaves that develop as a result of drought stress.

Materials and Methods

Materials

This study was carried out in Malatya Fruit Research Institute between 2001-2002. The research area is located at 38º 21′ north latitude and 38º 17′ east longitude, with an altitude of 980 m.

In the study, 2-year-old saplings of Kabaasi, Hacihaliloglu, Hasanbey, Cataloglu, Soganci apricot varieties grown in the region were planted in 8-liter pots in a glass greenhouse.

The soil mortar was prepared from sand: loamy soil: peat: farm fertilizer in the ratio of 1:2:1:0.5 (Hartmann and Kester, 1974). The mortar sample was found to have a field capacity of 23.77%, a wilting point of 12.20%, a texture of 54.26% sand, 23.63% silt and 22.11% clay; a texture class of SCL, a specific gravity of 2.63 g/cm3 and a bulk density of 1.12 g/cm3.

Drought Resistance Test

In drought resistance test, methods defined by Ozbek et al. (1976) and Tuzuner (1983) were used to determine the amount of water given to the plants. Accordingly, four different irrigation programs were applied to the plants, 100%, 75%, 50% and 25% of the available water, calculated using the field capacity (usable moisture capacity) and wilting point values of the mortar mixture. At the beginning of the tests, the irrigation level given to the plants was cut off, and the determined irrigation program was applied.

This test, which aims to determine the resistance levels of saplings to drought conditions created by reducing the amount of usable water at specific rates, started on June 12 in 2001 and June 20 in 2002, as the most suitable period for drought tests in outdoor conditions. Irrigation provided to the saplings at sufficient levels and evenly until these dates, was cut off and the usable water in the plant root zone was expected to decrease to 75%, 50% and 25%. In 100% applications, sufficient irrigation was continued. During the trial, saplings were kept at the targeted irrigation levels and re-irrigation was performed when 20% of each irrigation level was consumed (Gunbatili, 1979). For irrigation, the amount of water to be given was determined by weighing the pots in the morning, and then the missing water was completed to the desired level (Steinberg et al., 1990). During the test period, no fertilization or pesticide applications were made to ensure homogenization. The yellowing and shedding of the first few leaves were taken as the beginning of stress (Proebsting and Middleton, 1980).

The trial was organized according to the randomized plot design, with three replications for each application and three saplings in each replication, based on varieties.

Chlorophyll And Carotenoid Contents

Chlorophyll and carotenoid contents were determined by taking three leaves that completed their development in the middle part of young shoots of each sapling at 15-day intervals throughout the experiment. For this purpose, 1 g of leaf sample ground in the dark was taken and subjected to extraction with 90% acetone. Since chlorophyll can quickly decompose in light, it is essential to have a light-free environment and to cover the laboratory equipment used with aluminum foil during the analyses. Then, the absorbance values of the samples were read with the help of a spectrophotometer (Shimatsu brand, UV-120-01 model) at 662, 645 and 470 nm wavelengths. According to Lichtenthaler and Welburn (1983), chlorophyll-a (KL-a), chlorophyll-b (KL-b). Carotenoid contents of the leaves were calculated from the following formulas and the results were given in g/g fresh weight.

$$\text{Chlorophyll-a} = 11.75 \times A_{662} - 2.35 \times A_{645}$$
$$\text{Chlorophyll-b} = 18.61 \times A_{645} - 3.96 \times A_{662}$$
$$\text{Carotenoid} = [1000\ (A_{470}) - 2.27(\text{Cl-a}) - 81.4(\text{Cl-b})] / (227 \times 1000)$$

Total Sugar

Total sugar content of the samples was determined by the spectrophotometric method described by Dimler et al. (1952), which was developed for dried leaf samples. Based on the repetitions of the applications, 20 leaf samples taken from previously selected saplings at 15-day intervals were dried in the oven at 60°C for 48 hours and then ground in a mortar to make powder. 0.1 g of this sample was extracted with 25 ml of 80% ethyl alcohol. Absorbance values were created at 620 nm wavelength and evaluated with a standard curve drawn using pure glucose before the study. The results are given in mg/100 g dry weight and presented by combining two years of data.

Total Starch

Starch contents of leaf samples of the applications were determined by the spectrophotometric method described by Dimler et al. (1952). 0.1 g of the samples prepared for total sugar analysis were taken, hydrolyzed with concentrated sulfuric acid (5 ml) and diluted with distilled water (1:10 v). Absorbance values were made at 620 nm wavelength and evaluated with a standard curve drawn using pure starch before the study. The results are given in mg/100 g dry weight and presented by combining two years of data.

Abscisic Acid

For determining abscisic acid (ABA) content in leaves, extraction, purification,and analysis processes were carried out according to the method described by Yurekli et al. (1974). Depending on the replications formed in the irrigation applications in the drought resistance tests, one plant was marked in each replication before the study. Accordingly, 20 leaf samples that completed their development in the middle part of the shoots were used between 12.00-13.00 with 15-day intervals. For thin layer chromatography, 20x20 cm prepared plates coated with silica gel containing an inorganic fluorescent compound (Merck) were used. To determine the ABA regions, the plates were examined in a dark room under UV light at 254 nm wavelength. The ABA region belonging to the extract gave a purple fluorescence color, which showed a purple fluorescence color on the plate and was compared with the standard synthetic-ABA region. ABA amounts was made by ABA amounts were determined using 5 different concentrations of standard synthetic ABA and a Desaga CD60 scanning densitometer.

Statistical Analysis

In the statistical evaluation of the obtained data, two-way variance analysis and LSD test were used to determine the differences between the means. Statistical evaluations were carried out using the “SPSS 10.0 for Windows” program.

Results and Discussion

Amounts of Water

Statistically significant differences were determined between varieties in terms of the amount of water given. For 25% and 50% irrigation rates, the least irrigation water was given to Hasanbey, Kabaasi and Cataloglu varieties, while the amount of water given to Hacihaliloglu and Soganci varieties was higher than the other varieties. Among the irrigation rates, the difference in the amounts of irrigation water used for 25% and 50% compared to 75% and 100% irrigation water rates was found to be statistically significant. It is noteworthy that the amount of irrigation water applied for each irrigation rate in the Hacihaliloglu variety did not show a statistically significant difference (Table 1).

When the varieties were examined in general in the trial, plant water consumption was also the least in the varieties that observed as having the highest resistance. For example, the amounts of water given to the Kabaasi variety which showed almost no signs of stress at 25% irrigation rate, were found to be significantly lower than the Hacihaliloglu variety which showed the most signs of stress. This situation suggested that the Kabaasi variety may have a higher ability to benefit from the available water.

In the study of irrigation practices and internal water balance, it is recommended to work primarily with young trees. It is emphasized that this period is a more critical period in drought. Similarly, it has been stated that early drought resistance performance affects the future performance of the plant stress (Jackson et al., 1986; Proebsting et al., 1977).

Chlorophyll Contents

Chlorophyll a content was significantly higher in Kabaasi and Hasanbey varieties than in other varieties in both years. The lowest chlorophyll values were usually seen in the Hacihaliloglu and Cataloglu varieties. The chlorophyll a contents of Kabaasi variety were found to be significantly higher in 2001 at 25% irrigation rate and in 2002 at 50% irrigation rate than in all other varieties. In addition, an increase in chlorophyll a content was observed in both years parallel to the increase in irrigation rate and this was especially evident at 75% and 100% irrigation rates (Table 2).

Generally, Kabaasi and Hasanbey varieties, which were observed to be least affected by stress, were analyzed to contain more chlorophyll-a than other varieties. This situation was primarily mainly determined for Kabaasi variety at 25% and 50% irrigation rates, where they were most stressed. Chlorophyll b content, similar to chlorophyll a values, was found to be higher in Kabaasi and Hasanbey varieties than in other varieties in both years. This difference was more pronounced and statistically significant, especially in 2002. An increase in chlorophyll-b content was also observed with the increasing-rise in irrigation rate, which was especially evident in 2002 at 75% and 100% irrigation rates (Table 3).

Table 1. Effect of different irrigation levels on the amount of water (kg) replaced in the saplings of different apricot varieties. When 20% of each irrigation level was consumed, the lost water was completed to the desired level.

Variety	Irrigation rate (%)				Mean
	25	50	75	100	
Hacihaliloglu	13.26 cd	13.17 d	13.28 cd	13.25 cd	13.24 a
Cataloglu	12.68 f	12.78 e	13.53 ab	13.29 cd	13.07 b
Hasanbey	12.50 g	12.66 f	13.36 bcd	13.31 cd	12.96 c
Kabaasi	12.74 f	12.93 e	13.21 d	13.06 d	12.99 bc
Soganci	13.11 d	13.07 d	13.43 bc	13.63 a	13.31 a
Mean	12.86 b	12.92 b	13.36 a	13.31 a	

$LSD_{\%5}$ variety: 0.091**, irrigation rate: 0.081**, variety*irrigation rate: 0.181**

Table 2. Effect of different irrigation levels on chlorophyll-a content (μg/g fresh weight) in the leaves of different apricot varieties

Year	Variety	Irrigation rate (%)				Mean
		25	50	75	100	
2001	Hacihaliloglu	1.109 c	1.094 c	1.229 ac	1.123 c	1.139 b
	Cataloglu	1.087 c	1.189 c	1.147 c	1.164 bc	1.147 b
	Hasanbey	1.120 c	1.269 ac	1.395 a	1.363 a	1.287 a
	Kabaasi	1.389 a	1.379 a	1.242 ac	1.331 ab	1.336 a
	Soganci	1.073 c	1.140 c	1.254 ac	1.245 abc	1.177 b
	Mean	1.156 b	1.214 ab	1.254 a	1.246 a	
2002	Hacihaliloglu	1.523 e	1.957 cd	2.081 bc	2.317 ab	1.969 c
	Cataloglu	1.768 de	1.711 d	2.159 b	2.427 a	2.016 c
	Hasanbey	1.979 cd	1.881 cd	2.520 a	2.417 a	2.199 b
	Kabaasi	2.015 cd	2.426 a	2.558 a	2.482 a	2.375 a
	Soganci	1.819 d	1.824 d	1.836 cd	2.113 b	1.894 c
	Mean	1.821 d	1.960 c	2.231 b	2.352 a	

Year 2001: $LSD_{\%5}$ variety: 0.091**, irrigation rate: 0.081**, variety*irrigation rate: 0.182**; Year 2002: $LSD_{\%5}$ variety: 0.124**, irrigation rate: 0.111**, variety*irrigation rate: 0.248**

Table 3. Effect of different irrigation levels on chlorophyll-b content (µg/g fresh weight) in the leaves of different apricot varieties

Year	Variety	Irrigation rate (%)				Mean
		25	50	75	100	
2001	Hacihaliloglu	1.839	1.880	2.090	1.906	1.929 b
	Cataloglu	1.777	1.856	2.766	2.000	2.100 ab
	Hasanbey	2.236	2.017	2.271	2.138	2.166 ab
	Kabaasi	2.316	2.177	2.229	3.196	2.480 a
	Soganci	2.041	1.749	1.914	1.914	1.905 b
	Mean	2.042	1.936	2.254	2.231	
2002	Hacihaliloglu	1.543 d	1.842 cd	2.508 a	2.166 bc	2.015 b
	Cataloglu	1.641 d	1.698 d	1.892 cd	2.088 bc	1.830 bc
	Hasanbey	2.064 bc	1.936 cd	2.659 a	2.509 a	2.292 a
	Kabaasi	1.905 cd	2.326 a	2.470 a	2.451 ab	2.288 a
	Soganci	1.617 d	1.653 d	1.858 cd	2.083 bc	1.802 c
	Mean	1.754 b	1.891 b	2.278 a	2.260 a	

Year 2001: $LSD_{\%5}$ variety: 0.560**, irrigation rate: ns, variety*irrigation rate: ns ; Year 2002: $LSD_{\%5}$ variety: 0.198**, irrigation rate: 0.178**, variety*irrigation rate: 0.397**

Table 4. Effect of different irrigation levels on carotenoid content (µg/g fresh weight) in the leaves of different apricot varieties

Year	Variety	Irrigation rate (%)				Mean
		25	50	75	100	
2001	Hacihaliloglu	0.920	1.186	0.842	0.939	0.972 ab
	Cataloglu	0.901	1.004	0.618	0.950	0.868 b
	Hasanbey	0.976	1.180	1.029	1.006	1.048 a
	Kabaasi	1.052	1.113	0.919	0.781	0.966 ab
	Soganci	1.069	0.925	0.974	0.919	0.972 ab
	Mean	0.984 ab	1.081 a	0.877 b	0.919 ab	
2002	Hacihaliloglu	1.171 d	1.236 cd	1.232 cd	1.553 ab	1.291 b
	Cataloglu	1.177 d	1.323 cd	1.254 cd	1.454 bc	1.302 b
	Hasanbey	1.219 d	1.282 cd	1.548 ab	1.498 bc	1.387 b
	Kabaasi	1.490 bc	1.630 ab	1.742 a	1.761 a	1.656 a
	Soganci	1.392 cd	1.291 c	1.416 bc	1.018 e	1.279 b
	Mean	1.284 c	1.352 bc	1.439 ab	1.457 a	

Year 2001: $LSD_{\%5}$ variety: 0.178**, irrigation rate: 0.196*, variety*irrigation rate: ns; Year 2002: $LSD_{\%5}$ variety: 0.111**, irrigation rate: 0.099**, variety*irrigation rate: 0.221**

Various studies have shown that the chlorophyll content in plants decreases as a result of its breakdown due to stress caused by water limitation (Marler et al., 1994; Eris et al., 1998; Kumar et al., 2023). Studies on cherry (Kırnak and Demirtas, 2002), plum (Kaynas and Kaynas, 1999; Laita et al., 2024) and apricot (Ali and Nazar, 2023) have also reported that leaf chlorophyll content varies depending on the amount of water given to the plant. Consistent with these findings, it was determined that there was a decrease in leaf chlorophyll-a and chlorophyll-b contents at low irrigation rates in apricots in our study.

Plants with low chlorophyll reduction rates have been reported to be more tolerant to drought stress (Arunyanark et al., 2008; Talebi, 2011; Nofrizal, 2022). Similarly, in our study, the change in chlorophyll content was at the lowest rate in Kabaasi and Hasanbey varieties, which are thought to be most resistant to drought stress. The decrease in chlorophyll content under drought conditions may reflect the decrease in photosynthetic capacity and thus the weakening of drought resistance of plants. On the other hand, studies indicate that there is no relationship between the change in chlorophyll content and drought resistance (Buxton et al., 1985; Tsiupka et al., 2023).

Carotenoid Contents

In 2001, the values in the Hasanbey variety were found to be significantly higher than the Cataloglu variety in terms of carotenoid content (Table 4).

In 2002, the carotenoid content of the Kabaasi variety was detected to be statistically significantly higher than the other varieties. An increase in carotenoid content was also observed due to increased irrigation rates. However, the highest values for each irrigation rate were measured in the Kabaasi variety (Table 4).

Carotenoids are terpenoid pigments synthesized via the isoprenoid pathway and play a critical role in reducing oxidative stress. Drought stress negatively affects cellular functions by reducing water potential in plants. Under drought stress, ROS production increases in plants and these molecules can damage cellular components. Carotenoids reduce cellular damage by neutralizing ROS and increase the resistance of plants to drought stress (Niyogi, 1999; Fang and Xiong, 2015). Stonefruit species have high carotenoid content. These fruits increase carotenoid levels when exposed to drought stress, keep ROS accumulation under control and protect the integrity of cell membranes. In this process, plant growth regulators (e.g., abscisic acid) also support the drought response by regulating carotenoid metabolism (Qin and Zeevaart, 1999; McQuinn and Waters, 2024). In our study, supporting these findings, carotenoid contents were generally found to be high in Kabaasi and Hasanbey varieties, which were observed to have high drought tolerance. In particular, the highest carotenoid value was measured in Kabaasi variety at 25% irrigation rate in the 2nd year, indicating that carotenoid content may be critical-essential physiological parameter in drought resistance.

Table 5. Effect of different irrigation levels on total sugar content (mg/100 g dry weight) in the leaves of different apricot varieties

Variety	Irrigation rate (%)				Mean
	25	50	75	100	
Hacihaliloglu	4.140	4.083	4.227	3.915	4.091 a
Cataloglu	3.697	3.710	3.673	3.400	3.620 b
Hasanbey	3.936	3.918	3.600	3.620	3.768 ab
Kabaasi	3.672	3.596	3.421	3.476	3.541 b
Soganci	3.840	3.811	3.627	3.721	3.750 ab
Mean	3.857	3.824	3.710	3.626	

$LSD_{\%5}$ variety: 0.461**, irrigation rate: ns, variety*irrigation rate: ns

Table 6. Effect of different irrigation levels on total starch content (mg/100 g dry weight) in the leaves of different apricot varieties

Variety	Irrigation rate (%)				Mean
	25	50	75	100	
Hacihaliloglu	2.878	3.446	3.803	3.531	3.415
Cataloglu	3.600	3.773	3.711	3.777	3.715
Hasanbey	3.081	3.615	3.573	4.026	3.574
Kabaasi	3.587	3.905	4.777	4.047	4.079
Soganci	3.506	3.926	3.822	3.917	3.793
Mean	3.330	3.733	3.937	3.860	

$LSD_{\%5}$ variety: ns, irrigation rate: ns, variety*irrigation rate: ns

Table 7. Effect of different irrigation levels on abscisic acid content (µg/100 g) in the leaves of different apricot varieties

Year	Variety	Irrigation rate (%)				Mean
		25	50	75	100	
2001	Hacihaliloglu	475.95	254.83	188.65	125.38	261.20
	Cataloglu	363.73	377.71	256.51	291.10	322.26
	Hasanbey	313.45	346.56	296.58	297.91	313.62
	Kabaasi	478.41	297.75	237.95	241.26	313.84
	Soganci	262.43	256.78	163.71	187.50	217.60
	Mean	378.79 a	306.72 ab	228.68 b	228.63 b	
2002	Hacihaliloglu	421.48	451.30	95.63	69.96	259.59
	Cataloglu	359.43	300.41	183.23	242.32	271.35
	Hasanbey	440.93	207.90	226.50	187.85	265.79
	Kabaasi	407.77	315.41	179.88	199.60	275.66
	Soganci	411.23	249.32	208.03	176.05	261.16
	Mean	408.16 a	304.86 ab	178.65 b	175.15 b	

Year 2001: $LSD_{\%5}$ variety: ns, irrigation rate: 146.12*, variety*irrigation rate: ns; Year 2002: $LSD_{\%5}$ variety: ns, irrigation rate: 175.30*, variety*irrigation rate: ns

Total sugar Contents

The highest total sugar content was found in Hacihaliloglu variety, while the lowest total sugar content was found in Kabaasi and Cataloglu varieties (Table 5). According to irrigation practices, the highest total sugar content was found at 25% irrigation rate, indicating that the plants were under stress and a decrease in total sugar content was observed as the irrigation rate increased. However, these differences did not occur at the level of statistical significance (Table 5).

In various studies, consistent with our findings, it has been shown that as the amount of irrigation water given to the plants decreases, the total amount of sugar in the leaves increases (Balasimha et al., 1987; Pomper and Breen, 1997; Shinozaki and Yamaguchi-Shinozaki, 2007). In some studies on apricots, it has been reported that water restriction can improve fruit quality by increasing the total sugar amount in the fruit without significantly affecting tree yield, and the importance of irrigation strategies appropriate to varieties has been emphasized (Falchi et al., 2020).

Total starch Contents

Although there was no statistically significant difference between the varieties, the highest starch content was analyzed in the Kabaşı variety and the lowest in the Hacihaliloglu variety. The increase in starch content with the rise in irrigation rate was evident starting from 50% irrigation rate in the varieties. However, these findings showed no statistically significant difference (Table 6).

Plants under drought stress meet their energy needs by increasing starch degradation and regulating cellular osmotic pressure. Starch degradation can facilitate plant adaptation to water stress; however, excessive starch degradation can have adverse effects in the long term by depleting plant energy reserves (Chaves et al., 2003). Due to the alternating change between carbohydrate forms in plants with water restriction, the amount of leaf starch has a trend opposite to the shift in sugar (Munns and Weir, 1981; Fuhrt and Lenz, 1989). Similarly, in our study, there was a decrease in the starch content of the leaves as the irrigation rate decreased; however, this difference was not found to be statistically significant.

Although it has been reported that starch content decreases in response to drought in general, this situation does not always occur. The degree of changes in starch content depends on the plant species, the duration of exposure to stress and environmental factors (Hasan et al., 2023). Our study found the lowest values in the Hacihaliloglu variety, especially at 25% irrigation rate, where the plants were under the most stress.

Abscisic acid Contents

In both years, no statistically significant difference was found between the varieties in terms of ABA contents; however, in 2001, the lowest ABA contents were observed in Hacihaliloglu and Soganci varieties, which generally showed the most stress symptoms (Table 7). On the other hand, with the increase in irrigation rate, a decrease was observed in the ABA content of the varieties in both years. It was determined that the ABA amounts at 25% irrigation rate were significantly higher than the values at 75% and 100% irrigation rates. In particular, a significant decrease was detected in the ABA content of Hacihaliloglu variety starting from 75% irrigation rate (Table 7).

Stonefruits use a variety of physiological and physiological strategies to cope with drought, and ABA is central to these processes. Under water stress, ABA levels in plants increase, triggering a variety of physiological responses such as stomatal closure. In this way, plants reduce water loss through transpiration (Zhang et al., 2006). In our previous study, we demonstrated that the Kabaasi variety, identified as the most drought-resistant, exhibited stomatal closure at varying degrees depending on irrigation levels. Microscopic analysis revealed that even at a 75% irrigation rate, which was a minimal stress, the stomata of the Kabaasi variety were partially closed; whereas in the Hacihaliloglu variety, the stomata remained largely open under the same irrigation conditions (Olmez et al., 2010). ABA also helps plants adapt to low water conditions by increasing the expression of drought-related genes, such as promoting the synthesis of antioxidant enzymes that protect cells from damage caused by oxidative stress (Zhang et al., 2009; Cutler et al., 2010; Wilkinson and Davies, 2010). Increased ABA levels in plants stressed by reduced water supply or under drought conditions have been explained in many studies (Hiron and Wright, 1973; Eriş and Kaynaş, 1995; Jalili et al., 2023). Parallel to this information, in our research, ABA values, which were relatively high at 25% irrigation rate, showed a significant decrease especially starting from 75% irrigation rate. These decreases were detected most clearly in Hacihaliloglu variety, which was observed to be most affected by water stress. This may suggest that ABA mechanism is more activated in sensitive varieties under water limitation.

Conclusion

The current study was conducted to determine the physiological changes at different irrigation rates in essential varieties grown in the Malatya region, where apricot production is intensive, and their relationship with the drought resistance of the varieties.

The primary purpose of the irrigation programs is to keep the trees at minimum stress in order to get the maximum product. Regular limited water applications are recommended to the trees, especially during the period when vegetative development accelerates.

In physiological evaluations, chlorophyll values in the leaves decreased depending on the water deficit rates. The change in chlorophyll content was at the lowest rate in Kabaasi and Hasanbey varieties, which are thought to be most resistant to water deficit. In Hacihaliloglu, Soganci and Cataloglu varieties, chlorophyll contents were lower, especially at 25% irrigation. In order to increase the resistance to drought stress in fruit trees, monitoring of chlorophyll content and implementation of appropriate genetic improvement strategies can be recommended. In terms of carotenoid content, the highest values were determined in Hasanbey and Kabaasi varieties. Many studies have confirmed that carotenoids to resist drought stress in stone fruits. The antioxidant functions of carotenoids and their interactions with plant growth regulators these fruits' survival and productivity capacities under drought conditions.

Total sugar content was the highest in Hacihaliloglu, the lowest in Kabaasi and Hasanbey varieties. The highest values of total starch content, which is expected to have an inverse interaction with total sugar and stress, were determined in Kabaasi variety, especially at 25% and 50% irrigation rates, and the lowest in Hacihaliloglu variety. It provides crucial-essential information in understanding the relationship between drought resistance and total sugar in stone fruit species. These findings confirmed that plants with high drought resistance generally have lower sugar content.

Abscisic acid is critical in regulating drought resistance in stone fruit species. ABA is central in controlling water use, strengthening stress response mechanisms, and increasing plant resistance in water-limited conditions. The Hacihaliloglu variety, which was found to be sensitive in terms of ABA content, which is expected to increase due to stress, had high values under restricted irrigation conditions, while it showed the most significant decrease at a 75% irrigation rate.

Consequently, it was concluded that Kabaasi was the most drought-resistant variety, followed by Hasanbey, while Hacihaliloglu, the most common variety in the region, was the most susceptible to drought. Although all varieties exhibited signs of stress at 25% irrigation, they generally managed to tolerate stress at 50% irrigation. Due to global warming and the related drought problem that has increasingly threatened our country in recent years; developing new, variety-specific irrigation strategies that consider the periods during which varieties can endure drought and their minimum irrigation water requirements is crucial for enhancing water use efficiency. Additionally, understanding the drought resistance of these important varieties will offer valuable information for cross-breeding programs focused on developing new drought-resistant candidate varieties.

Declarations

Ethical Approval Certificate

Not necessary

Author Contribution Statement

H.O.: Project administration, data collection, investigation, writing the original draft

B.C.: Data collection and investigation, methodology

A.M.: Supervision, review and editing

Fund Statement

This work was funded by The Scientific and Technological Research Council of Turkiye (TUBITAK, project no: 2573-14)

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgement

This research was supported by The Scientific and Technological Research Council of Turkiye (TUBITAK, project no: 2573-14)

References

Aghanejad, M., Mahfoozi, S., & Sharghi, Y. (2015). Effects of Late-Season Drought Stress on some Physiological Traits, Yield and Yield Components of Wheat Genotypes. Biological Forum-An International Journal, 7(1), 1426-1431. https://doi.org/10.15244/pjoes/85350

Ali, T. A., & Nazar, H. M. (2023). Response of Royal prunus armeniaca L. Apricot Trees to Humic Acid and Microelements Fertilization. In IOP Conference Series: Earth and Environmental Science, 1158 (9), 092005. https://doi.org/10.1088/1755-1315/1158/9/092005

Anjum, S. A., Xie, X., Wang, L., Saleem, M. F., Man, C., & Lei, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. African Journal of Agricultural Research, 6, 2026-2032. https://doi.org/10.5897/AJAR10.027

Arunyanark, A., Jogloy, S., Akkasaeng, C., Vorasoot, N., Kesmala, T., Nageswara Rao, R. C., & Patanothai, A. (2008). Chlorophyll stability is an indicator of drought tolerance in peanut. Journal of Agronomy and Crop Science, 194(2), 113-125. https://doi.org/10.1111 /j.1439-037X.2008.00299.x

Balasimha, D., Rajagopal, V., Daniel, E.V., Nair, R.V. & Bhagavan, S. (1988). Comparative drought tolerance of cacao accessions. Tropical Agriculture, 65(3).

Bing, Y. I., Zhou, Y. F., Gao, M. Y., Zhang, Z., Yi, H. A. N., Yang, G. D., & Huang, R. D. (2014). Effect of drought stress during flowering stage on starch accumulation and starch synthesis enzymes in sorghum grains. Journal of Integrative Agriculture, 13(11), 2399-2406. https://doi.org/10.1016/S2095-3119(13)60694-2

Buxton, G. F., Cyr, D. R., Dumbroff, E. B., & Webb, D. P. (1985). Physiological responses of three northern conifers to rapid and slow induction of moisture stress. Canadian journal of botany, 63(7), 1171-1176.

Chalmers, D.J., Burge, G., Jerie, P.H. & Mitchell, P.D. (1986). The mechanism of regulation of 'Barlett' pear fruit and vegatative growth by irrigation withholding and regulated deficit irrigation. Journal of the American Society for Horticultural Science, 111, 904-907.

Chaves, M. M., Maroco, J. P., & Pereira, J. S. (2003). Understanding plant responses to drought-from genes to the whole plant. Functional Plant Biology, 30(3), 239-264. https://doi.org/10.1071/FP02076

Cutler, S. R., Rodriguez, P. L., Finkelstein, R. R., & Abrams, S. R. (2010). Abscisic acid: emergence of a core signaling network. Annual Review of Plant Biology, 61, 651-679. https://doi.org/10.1146/annurev-arplant-042809-112122

Dimler, F.G., Shaster, N.C. & Crist, C. (1952). Quantative paper chromotography of D-glucose and its oligosuccharites. Analytical Chemistry, 24, 1411-1414.

Eris, A. & Kaynas, N. (1995). Bazı şeftali çeşitlerinde kuraklığın içsel ABA değişimine etkileri. Türkiye II. Ulusal Bahçe Bitkileri Kongresi, 3-6 Ekim, Adana.

Eris, A., Sivritepe, N. & Sivritepe, H.O. (1998). Asmalarda su stresine karşı ortaya çıkan bazı morfolojik ve fizyolojik reaksiyonlar. 4. Bağcılık Sempozyumu, 20-23 Ekim, Yalova, 64-69

Falchi, R., Bonghi, C., Drincovich, M. F., Famiani, F., Lara, M. V., Walker, R. P., & Vizzotto, G. (2020). Sugar metabolism in stone fruit: Source-sink relationships and environmental and agronomical effects. Frontiers in plant science, 11, 573982. https://doi.org/10.3389/fpls.2020.573982

Fang, J., & Xiong, L. (2015). General mechanisms of drought response and their application in drought resistance improvement in plants. Cellular and Molecular Life Sciences, 72(4), 673-689. https://doi.org/10.1007/s00018-014-1767-0

Fuhrt, B. & Lenz, F. (1989). Photosynthese von apfelblattern bei unter-schiedlicher wasserversorgung. Mitt. Klosterneu-burg, 39, 191-195.

Ghahremani, A., Moghaddam, E. G., & Marjani, A. (2023). Growth, yield, and biochemical behaviors of important stone fruits affected by plant genotype and environmental conditions. Scientia Horticulturae, 321, 112211. https://doi.org/10.1016/j.scienta.2023.112211Get rights and content

Günbatılı, F. (1979). Tokat-Kazonova koşullarında şeftalinin su tüketimi. Topraksu Genel Müd. Genel Yayın No.35:40

Hartmann, H.T. & Kester, D.E. (1974). Plant propagation, principles and practices (çev. N. Kaska ve M. Yılmaz), Ç. Ü. Fak. Yay. No:79: 610 s.

Hasan, M. M., Alabdallah, N. M., Salih, A. M., Al-Shammari, A. S., ALZahrani, S. S., Al Lawati, A. H. & Fang, X. W. (2023). Modification of starch content and its management strategies in plants in response to drought and salinity: current status and future prospects. Journal of Soil Science and Plant Nutrition, 23(1), 92-105. https://doi.org/10.1007/s42729-022-01057-7

Kaynas, N. & Kaynas, K. (1999). Bazı erik klon anaçlarının kurağa dayanımları. Türkiye III. Ulusal Bahçe Bitkileri Kongresi. 111-115, Ankara, 14-17 Eylül.

Keunen, E. L. S., Peshev, D., Vangronsveld, J., Van Den Ende, W. I. M., & Cuypers, A. N. N. (2013). Plant sugars are crucial players in the oxidative challenge during abiotic stress: extending the traditional concept. Plant, cell & environment, 36(7), 1242-1255. https://doi.org/10.1111/pce.12061

Kirnak, H. & Demirtas, M.N. (2002). Su stresi altındaki kiraz fidanlarında fizyolojik ve morfolojik değişimlerin belirlenmesi. Atatürk Üniv. Ziraat Fak. Dergisi, 33(3), 265-270.

Laita, M., Sabbahi, R., Elbouzidi, A., Hammouti, B., Messaoudi, Z., Benkirane, R., & Aithaddou, H. (2024). Effects of sustained deficit irrigation on vegetative growth and yield of plum trees under the semi-arid conditions: Experiments and review with bibliometric analysis. ASEAN Journal of Science and Engineering, 4(2), 167-190. https://doi.org/10.17509/ajse.v4i2.64600

Lichtenthaler, H.K. & Welburn, A.R. (1983). Determination of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. Biochemical Society Transactions, 11 (5), 591-592. https://doi.org/10.1042/bst0110591

Hasdemir, M. (2023). Kayısı Ürün Raporu, Tarımsal Ekonomi Ve Politika Geliştirme Enstitüsü (TEPGE),. https://arastirma.tarimorman.gov.tr/tepge/

Hiron, R.W.P. & Wright, S.T.C. (1973). The role of endogenous abscisic acid in the response of plants to stress. Journal of Experimental Botany, 24, 769-781.

Jackson, L.K., Summerhill, W.R. & Ferguson, J.J. (1986). A survey of young citrus tree care practices in Florida . Proceedings of the Florida State Horticultural Society, 99, 44-46.

Jalili, S., Arzani, K., Prudencio, A. S., Salazar, J. A., Martínez-García, P. J., Bouzari, N., & Martínez-Gómez, P. (2023). Integrated Morphological, Physiological and Molecular Analysis of the Drought Response in Cultivated and Wild Prunus L. Subgenera Cerasus Species. Plant Molecular Biology Reporter, 41(3), 440-453. https://doi.org/10.1007/s11105-023-01379-5

Kumar, A., Sharma, N., Wani, T. F., & Sharma, R. (2023). Water productivity of temperate fruits in climate change scenario. In Advances in water management under climate change (pp. 210-235). CRC Press

Liu, X., Gao, T., Liu, C., Mao, K., Gong, X., Li, C., & Ma, F. (2023). Fruit crops combating drought: Physiological responses and regulatory pathways. Plant Physiology, 192(3), 1768-1784. https://doi.org/10.1093/plphys/kiad202

Marler, T.E., Schaffer, B. & Crane, J.H. (1994). Developmental light level affects growth, morphology, and leaf physiology of young carambola trees. Journal of the American Society for Horticultural Science, 119(4), 711-718. https://doi.org/10.21273/JASHS.119.4.711

McQuinn, R. P., & Waters, M. T. (2024). Apocarotenoid signals in plant development and beyond. Journal of Experimental Botany, 75(4), 1131-1133. https://doi.org/10.1093/jxb/erae024

Mitchell, P. D., Ende, V. D., Jerie, P. H. & Chalmers, D. J. (1989). Response of 'Barlett' pear to withholding irrigation, regulated deficit irrigation and tree spacing. Journal of the American Society for Horticultural Science, 114, 15-19. https://doi.org/10.21273/jashs.114.1.15

Munns, R. & Weir, R. (1981). Contrubition of sugars to osmotic adjustment in elongating and expanded zones of wheat leaves during moderate water deficits at two light levels. Australian Journal of Plant Physiology, 8, 93-105. https://doi.org/10.1071/PP9810093

Niyogi, K. K. (1999). Photoprotection revisited: genetic and molecular approaches. Annual Review of Plant Biology, 50(1), 333-359. https://doi.org/10.1146/annurev.arplant.50.1.333

Nofrizal, A.Y.; Sonobe, R.; Yamashita, H.; Seki, H.; Mihara, H.; Morita, A., & Ikka, T. (2022). Evaluation of a one-dimensional convolution neural network for chlorophyll content estimation using a compact spectrometer. Remote Sensing, 14, 1997. https://doi.org/10.3390/rs14091997

Olmez, H. A., Gulcan, R. & Misirli, A. (2010). Bazı Kurutmalık Kayısı Çeşitlerinde Kuraklık Stresinde Oluşan Morfolojik Değişimlerin Belirlenmesi. I. Ulusal Sulama ve Tarımsal Yapılar Sempozyumu, 27-29 Mayıs, Kahramanmaraş.

Ozbek, H., Yesilsoy, M. Ş., Guzel, N., Berkman, A. & Kapur, S. A. (1976). Genel toprak bilimi uygulama notları. Cuk.Univ.Zir.Fak.Adana, p: 41.

Pomper, K. W. & Breen, P. J. (1997). Expansion and osmotic adjustment of strawberry fruit during water stress. Journal of the American Society for Horticultural Science, 122(2), 183-189. https://doi.org/10.21273/JASHS.122.2.183

Proebsting, E. L., Middleton, J. E. & Roberts, S. (1977). Altered fruiting and growth characteristics of 'Delicious' apple associated with irrigation method. Journal of the American Society for Horticultural Science, 12, 349-350. https://doi.org/10.21273/HORTSCI.12.4.349

Proebsting, E. L. & Middleton, J. E. (1980). The behavior of peach and pear trees under extreme drought stress. Journal of the American Society for Horticultural Science, 105:380-385. https://doi.org/10.21273/JASHS.105.3.380

Qin, X., & Zeevaart, J. A. (1999). The 9-cis-epoxycarotenoid cleavage reaction is the key regulatory step of abscisic acid biosynthesis in water-stressed bean. Proceedings of the National Academy of Sciences of the United States of America, 21, 96(26), 15354-61. https://doi.org/10.1073/pnas.96.26.15354.

Shinozaki, K., & Yamaguchi-Shinozaki, K. (2007). Gene networks involved in drought stress response and tolerance. Journal of Experimental Botany, 58(2), 221-227.

Steinberg, S.L., Miller, J.C. & McFarland, M.J. (1990). Dry matter partitioning and vegetative growth of young peach trees under water stress. Australian Journal of Plant Physiology, 17, 23-36. https://doi.org/10.1071/PP9900023

Talebi, R. (2011). Evaluation of chlorophyll content and canopy temperature as indicators for drought tolerance in durum wheat (Triticum durum Desf.). Australian Journal of Basic and Applied Sciences, 5, 1457–1462.

Tsiupka, V., Tsiupka, S., Plugatar, Y., Bulavin, I., & Komar-Tyomnaya, L. (2023). Assessment of the Drought-Tolerance Criteria for Screening Peach Cultivars. Horticulturae, 9(9), 1045. https://doi.org/10.3390/horticulturae9091045

Tuzuner, A. (1983). Toprak rutubetini değerlendirme yöntemleri. Toprak ve Gübre Araş. Ens. Yayın no: 118:13

Wilkinson, S., & Davies, W. J. (2010). Drought, ozone, ABA and ethylene: new insights from cell to plant to community. Plant, Cell & Environment, 33(4), 510-525. https://doi.org/10.1111/j.1365-3040.2009.02052.x

Yurekli, K., Guven, A., & Gork, G. (1974). Spektrofotometre ile büyüme hormonlarının kantitatif tayinleri üzerinde çalışmalar. Bitki, 1(1):60-68.

Zhang, J., Jia, W., Yang, J., & Ismail, A. M. (2006). Role of ABA in integrating plant responses to drought and salt stresses. Field Crops Research, 97(1), 111-119. https://doi.org/10.1016/j.fcr.2005.08.018

Zhang, Y., Tan, J., Guo, Z., Lu, S., He, S., Shu, W., & Zhou, B. (2009). Increased abscisic acid levels in transgenic tobacco over-expressing 9 cis-epoxycarotenoid dioxygenase influence H2O2 and NO production and antioxidant defences. Plant, cell & environment, 32(5), 509-519. https://doi.org/10.1111/j.1365-3040.2009.01945.x