



Agronomic and Biochemical Responses of Blackberry to Alternative Deficit Irrigation Strategies to Increase Stress Tolerance

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Abstract

Increasingly severe drought increases the demand for clean water resources, which necessitates the economical use of water, especially in arid and semi-arid areas. Determining the stress tolerance of plants under different irrigation strategies is very important for selecting suitable plants for regions with water shortages. This study aimed to determine the water–yield relationships of blackberry, which is a plant allowing production in small areas and has a high economic return. In the study, the response of two different blackberry varieties (‘Bursa II’ and ‘Chester’) to five different irrigation levels, including intermittent water stress (IWS) and continuous water stress (CWS), was assessed in field conditions for 2 years (2021 and 2022). As a result of the research, the highest plant water consumption was calculated in ‘Bursa II’ (C_B) and ‘Chester’ (C_C) varieties with 571.8 and 481.2 mm, respectively, in full irrigation (I₁₀₀) applications. The highest yield was obtained from C_BI₁₀₀ treatment as 1444.8 kg da⁻¹ and 1610.5 kg da⁻¹ in the 2021 and 2022 trial years, respectively, and significant decreases were recorded in fruit yield under severe water stress conditions. While decreases were observed in physiological parameters such as stomatal conductance and leaf relative water content (LRWC) with increasing water stress, the amount of substances that caused oxidative damage such as H₂O₂ and malondialdehyde increased. The results of the yield response factor (ky), an important parameter in evaluating the plant’s response to water stress, showed that blackberry, a perennial plant, can adapt to stress conditions. As a result, it was concluded that blackberry, which can tolerate moderate drought severity, can be recommended as an alternative plant for arid and semi-arid areas, and that it would be useful to try IWS on different plants sensitive to water restriction.

Keywords Drought stress · Plant physiology · Semi arid regions · Water use efficiency · Yield response factor

Introduction

Globally, food production obtained through irrigation represents more than 40% of total food production (Feres and Connor 2004). Agricultural irrigation accounting for approximately 74% of the water used worldwide is increasing its pressure on water resources day by day due to the effect of global warming. Rising surface temperatures and irregular rainfall regimes cause yield losses of up to 50%

due to drought in the world’s agricultural areas (Godoy et al. 2021; Sachdev et al. 2021) and threaten the sustainability of the food supply.

When plants encounter drought, they can dramatically restructure their metabolism, which can also change their life cycles, depending on the severity and duration of the stress (Srivastava et al. 2021; Munson et al. 2021). The response of plants to stress conditions begins with the perception of stress (Zhu 2016) and continues with signaling that activates stress-specific regulatory mechanisms (Maz-zucotelli et al. 2008; Yang et al. 2021). The first responses are the closure of stomata, minimizing photosynthesis and respiration. If the water lost by transpiration cannot be compensated by the roots, the water balance between plant organs is disrupted due to the negative pressure formed in the conduction pipes (Yüksel and Aksoy 2017; Lambers et al. 2019). With the onset of water loss in the cell, the membrane structure changes and passes into the gel phase. During this process, the cell volume decreases and rup-

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tures occur in the plasma membrane and the cell autolyzes (McKersie 1994). Plants synthesize a series of soluble substances known as “osmolytes” to avoid stress and maintain cell turgor balance (Serraj and Sinclair 2002; Ashraf and Harris 2004). The most important of these substances is proline, which is one of the first metabolic indicators of drought stress in plants (Liu et al. 2011). It is stated that proline, which reaches high concentrations under stress conditions, can protect plants against stress factors by acting in osmoregulation, reactive oxygen species (ROS) detoxification, resistance to membrane damage and regulating enzyme–protein activities (Ashraf 2009). While an increase in the amount of hydrogen peroxide (H_2O_2) and lipid peroxidation is observed in plants under drought stress, the effects of oxidative damage on membranes, which are the primary target of stress, can be observed with the analysis of malondialdehyde (MDA), which is one of the end products of this process (Hodges et al. 1999). Monitoring and assessing physiological, morphological and biochemical changes in plants allows us to better perceive the situation and intervene with the right approaches.

The application of different irrigation strategies is a very important approach to determine the resistance levels of plant species that can tolerate drought. Deficit irrigation is an irrigation strategy that has no alternative for arid and semi-arid areas (Zou et al. 2021; Yavuz and Yavuz 2023) and the potential to optimize water efficiency (Costa et al. 2007). Deficit irrigation applications allow us to save irrigation water without experiencing a significant loss in plant productivity (Pérez-Blanco et al. 2020). Although each plant responds differently to deficit irrigation (Ahluwalia et al. 2021), these responses vary according to the developmental stage of the plant and the level of water stress (Ru et al. 2020; Wagg et al. 2021). In order to determine the effect of water deficit on yield in the plant, yield values corresponding to different irrigation level applications must be determined under open field conditions (Doorenbos and Kassam 1979). It is very important to investigate the responses of blackberry, which has lower water consumption compared to many plants such as sugar beet, alfalfa and corn, to water stress in arid and semi-arid regions.

Blackberry, which can be found in almost every region of Turkey, is an important source of antioxidants as well as

rich in mineral and vitamin content (Schulz et al. 2019). It is known that antioxidants prevent oxidation, which increases tissue damage (Blokhina et al. 2003). Studies are being conducted on tannins found in blackberry fruit in order to obtain drugs against cancer (Rajasekar et al. 2021). The fact that blackberry is highly adaptable to different ecological conditions, easy to grow, and can obtain high yields from a unit area in a short period has led to an increase in the areas where it is cultivated economically. According to the latest data, 33,840 tons of blackberry were produced from 343 hectares of land in Turkey (TÜİK 2023). Although studies on the adaptation of blackberry varieties and the content of the fruit have been carried out (Balci and Keles 2019; Kurt et al. 2003; İpek and Arıkan 2024), studies on the water–yield relationship of the plant are limited in number (Dixon et al. 2015; Ciobotari et al. 2013). It has been observed that yield decreases linearly with water deficit in many plants (Lu et al. 2020; Yavuz et al. 2021; Liu et al. 2023; Seymen et al. 2024). Studies have been conducted on different crops using different irrigation strategies such as periodic deficit irrigation (Abd El-Mageed and Semida 2015; Pérez-Pérez et al. 2016), regular water restriction applications (Romero et al. 2022; Yavuz et al. 2023), and partial root dryness (PRD) (Gençoğlan et al. 2006; Campos et al. 2009). There is no comprehensive study in the literature relevant to the water–yield relationships of blackberry. The research was carried out both to determine the seasonal plant water consumption of blackberry in arid and semi-arid areas and to examine the changes in physiological, morphological and some biochemical properties of the plant at different irrigation levels. In addition, it was aimed to determine whether the different irrigation strategies applied in this trial could be an alternative to known deficit irrigation practices in terms of saving irrigation water.

Materials and Methods

Experimental Site

The research was carried out on the Konya-Selçuk University Campus (38°01'54"N 32°30'29"E, 1161 m), Turkey, in 2021 and 2022 (Supplementary Fig. S1). The trial land soil

Table 1 Some physical and chemical properties of the experimental area soils

Soil depth (cm)	pH	Organic matter (%)	Texture class	Bulk density ($g\ cm^{-3}$)	Field capacity		Wilting point		Total available water	
					m^3m^{-3}	mm	m^3m^{-3}	mm	m^3m^{-3}	mm
0–30	7.46	2.23	SiCL	1.47	0.359	107.7	0.204	61.2	0.155	46.5
30–60	7.51	1.97	SiC	1.39	0.347	104.1	0.186	55.8	0.161	48.3
			Total or average (0–60 cm)		0.353	211.8	0.195	117.0	0.158	94.8

SiCL Silty Clay Loam, SiC Silty Clay

Table 2 Some climatic parameters of the trial years and long-term averages

	Average Temperature (°C)		Average wind speed (m s ⁻¹)		Average relative humidity (%)		Total precipitation (mm)			
	2021	2022	1929–2022*	2021	2022	2021	2022	1929–2022*		
January	-2.6	-1.9	-0.2	2.6	2.8	78.2	79.2	25.2	70.6	38.4
February	1.8	1.5	1.5	1.9	2.6	76.4	79.3	11.9	48.0	28.8
March	4.8	3.8	5.5	2.5	3.8	64.8	69.4	51.1	55.1	29.4
April	11.9	13.5	11.1	2.3	3.1	55.2	41.0	29.1	1.0	31.7
May	16.2	14.9	15.9	2.2	2.9	56.4	55.1	2.0	39.9	43.0
June	22.8	20.6	20.1	2.3	3.5	48.2	51.0	47.1	10.4	25.9
July	23.8	21.9	23.5	2.8	4.1	42.9	40.6	26.3	7.9	7.5
August	23.7	25.2	23.3	2.5	3.3	41.8	38.9	9.8	2.0	6.3
September	17.3	19.9	18.8	2.3	2.6	55.0	40.1	29.1	11.5	13.5
October	11.2	12.9	12.8	1.7	2.8	53.5	61.0	2.7	24.2	29.6
November	8.9	8.0	6.5	1.7	1.8	66.6	65.1	16.0	10.9	32.0
December	1.9	5.0	1.8	1.1	1.6	79.2	78.6	88.4	7.9	45.7

*Long-term climate data of the region (93 years)

has a pH of 7.49, an electrical conductivity (EC) content of 1.04 dS m⁻¹, and its organic matter is 2.12%. The soil texture is silty-clay-loam having no drainage problem. According to the soil samples taken from the trial land, field capacity and wilting point values for 0–60 cm soil depth were determined as 0.353 and 0.195 m³/m³, respectively (Table 1). The quality of the water used is suitable for blackberry cultivation (C₂S₁).

In both trial years, some climatic data belonging to the research area were obtained from the meteorological station (Supplementary Fig. S2) established in the trial area, and long-term climate data (93 years) were obtained from the Konya Meteorological Regional Directorate and are presented in Table 2. The climatic data measured during the plant growth period in 2021 and 2022 are parallel to the long-term climate data of the region. The amount of precipitation during the vegetation period (May 1–October 1) in 2021 and 2022 was 114.3 and 71.7 mm, respectively.

Plant Materials, Irrigation System and Research Topics

As plant material, ‘Bursa II’, one of the most preferred varieties in Turkey, and ‘Chester’, relatively more suitable for warm climate conditions, were used. For both varieties, the distances between plant rows and on the rows were 2.5 m x 1 m, and the rows were covered with plastic mulch. The research was designed so that the length of the trial plots was 8 m and there would be eight plants in each plot. The drip irrigation system was composed of 16-mm diameter round drip irrigation pipes with 33-cm dripper spacing and 4 l h⁻¹ dripper flow rate, and 32-mm diameter manifold pipes.

In the research, two different blackberry cultivars (‘Bursa II’ and ‘Chester’), five different irrigation strategies (I₁₀₀: Full irrigation, I₁₀₀₋₇₀: One full irrigation–one 30% water stress; I₇₀: 30% water stress at each irrigation during the vegetation period, I₁₀₀₋₄₀: one full irrigation–one 60% water stress, I₄₀: 60% water stress at each irrigation during the vegetation period) were applied. In the study, irrigation was started in June in both years and ended in September. Irrigation water was applied to the plants once a week during this period and 10 experimental treatments were carried out in a split plot experimental design with three replications under field conditions.

Agricultural Practices

The study started in April by pruning 240 blackberry bushes of the ‘Bursa II’ and ‘Chester’ varieties aged 4 years. In May, the drip irrigation system was installed on the field in accordance with the trial treatments. When the blackberry shoots reached a certain length, the development of the plants was supported by pulling a wire. Necessary agri-

cultural practices were carried out in both trial years (Supplementary Fig. S3). During the trial cycle, soil moisture measurements were made regularly before each irrigation and the moisture content at the effective root depth was brought to the field capacity level. Fruit harvest started in July in both years and the harvest ended by the end of October.

Soil Moisture Content, Irrigation and Evapotranspiration (ET)

The gravimetric method was used as a basis for monitoring the moisture loss in the soil. Soil samples were taken from the of 0–30cm and 30–60cm depths in C_BI₁₀₀ and C_CI₁₀₀ treatments prior to irrigation processes. In addition, samples were taken from the depths of 60–90cm from the same plots after irrigation to monitor whether there was deep percolation.

The volume of irrigation water applied to the treatments as liter was determined with the equation below. Water meters were used to control the amount of irrigation water. Evapotranspiration (ET) was calculated according to the water budget method suggested by James (1988).

$$I_v = d_n \times A \times P_y \times I \quad (1)$$

- I_v = Irrigation water amount in volume (liters)
- d_n = Irrigation depth (mm)
- A = Plot area (20 m²)
- P_y = Coverage ratio (plant crown width/plant row width)
- I = Coefficient depending on irrigation levels
- (I₁₀₀:1.0; I₇₀:0.7; I₄₀:0.4; I₁₀₀₋₇₀:1.0–0.7; I₁₀₀₋₄₀:1.0–0.4)

Yield Response Factor (Ky), Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE)

In the study, the yield response factor (*ky*) showing the relationships between ET and yield was calculated by the equation developed by Doorenbos and Kassam (1979):

$$\left[1 - \frac{Y_a}{Y_m} \right] = ky \cdot \left[1 - \frac{ET_a}{ET_m} \right] \quad (2)$$

In the equation:

- *ky* = Yield response factor
- ET_m = Maximum evapotranspiration (mm)
- ET_a = Actual evapotranspiration (mm)
- Y_m = Maximum yield (kg da⁻¹)
- Y_a = Actual yield (kg da⁻¹)

In the study, blackberry yield was divided by ET to determine water use efficiency (WUE), and by irrigation water

amount to determine irrigation water use efficiency (IWUE) (Tanner and Sinclair 1983).

Fruit Characteristics

The total soluble solid (TSS), total acidity, and pH of the fruit juice were determined each harvest week. TSS and total acidity was determined by a digital refractometer (Atago PAL-BX/ACIDF5, Tokyo Tech). The pH of the fruit juice was determined with a pH meter.

Measurement of the Physiological Parameters

Leaf temperature and stomatal conductance were measured via LI-600 porometer/fluorometer (LI-COR Biosciences, Lincoln, NE, USA).

The SPAD-502 Plus, manufactured by Minolta Camera Co., Ltd. in Osaka, Japan, is a device used to assess chlorophyll content. It detects the leaf's absorbance in two specific wavelength ranges to determine the amount of chlorophyll present.

The membrane permeability (MP) was assessed using the approach described by Lutts et al. (1996). Electrolyte leakage was employed as a means of determining MP. The MP as a percentage was calculated using the following formula:

$$MP(\%) = \frac{EC_1}{EC_2} \times 100 \quad (3)$$

In order to determine the relative leaf water content (RLWC), fully developed leaves from both control and stress-treated plants were first evaluated for their fresh weight. Afterwards, the samples were placed in a magenta box filled with double-distilled water for a period of 4 h at room temperature to measure their turgid weight (hydration). The mass of the engorged leaves was measured, and then the leaves were desiccated in an oven at a temperature of 70 °C for a period of 48 h. The RLWC percentage was computed using the given formula:

$$RLWC(\%) = \frac{FW - DW}{TW - DW} \times 100 \quad (4)$$

FW is for the weight of a leaf when it is fresh, DW stands for the weight of a leaf when it is dry, and TW stands for the weight of a leaf when it is turgid (İpek and Pirlak 2016).

The Biochemical Content

The acid-ninhydrin technique (Bates et al. 1973) was employed to spectrophotometrically quantify the concentration

of proline. The findings were expressed as milligrams of proline per gram of fresh weight (mg proline g⁻¹ FW).

After homogenization of the leaf tissue using 5 mL of cold 0.1% trichloroacetic acid (TCA), the sample was centrifuged (Velikova et al. 2000). A phosphate buffer with a pH of 7.0 and potassium iodide (KI) solutions with a concentration of 1 mM were added to the supernatant in a volume of 0.5 mL. The permeability of the mixture was measured at a wavelength of 390 nm and the H₂O₂ concentration (mol g⁻¹ FT) was determined using a standard graph with the equation $y = 0.0353x - 0.0807$ and $R^2 = 0.9706$. The measurement of lipid peroxidation was conducted by quantifying the number of MDA equivalents, as described by Heath and Packer 1968.

Results and Discussion

Irrigation Amounts and Evapotranspiration (ET)

The amounts of irrigation water applied to the treatments are presented in Table 3. Among the blackberry varieties, ‘Bursa II’, which is better adapted to the climatic conditions of the region and reaches a greater biomass in accordance with the characteristics of the species, required more irrigation water than the ‘Chester’ variety. In 2021, the amounts of irrigation water applied to the ‘Bursa II’ variety varied between 418.7 mm (I₁₀₀) and 199.9 mm (I₄₀), while the amounts of irrigation water applied to the ‘Chester’ variety varied between 327.0 mm (I₁₀₀) and 152.4 mm (I₄₀) (Table 3). In the second year of the experiment, the irrigation water use of both varieties increased compared to the first year. It is thought that the plants needed more irrigation water in 2022 compared to 2021 due to reasons such as different shoot numbers and shoot lengths and seasonal changes in climatic conditions.

In the first year of the experiment, the highest ET value of blackberry was calculated as 537.2 mm in the fully irri-

gated ‘Bursa II’ variety. Increment in water stress reduced ET of blackberry, but decrease in ET was found lower comparison to decrease in irrigation water depth. The presence of moisture in the soil close to field capacity at the beginning of the vegetation period is an important factor in this result. The fact that the amount of precipitation affected all subjects equally is one of the reasons why plant water consumption does not decrease proportionally to the amount of irrigation water. Similarly, in a study conducted in Malatya conditions of Turkey, 404.97 mm of irrigation water was applied to the drip-irrigated ‘Bursa I’ blackberry variety and 493.53 mm to the ‘Chester’ variety. In the same study, 445.89 mm ET was calculated for ‘Bursa I’ and 542.45 mm for ‘Chester’ (Sakar Erdogan 2019). Seasonal evapotranspiration for the fruit group, including blackberry, in Serbian climatic conditions was reported as 552.4 mm (Ćosić et al. 2021).

Blackberry Yield and Yield Parameters

Different irrigation programs applied to ‘Bursa II’ (C_B) and ‘Chester’ (C_C) blackberry cultivars showed significant effects on yield and yield parameters (Fig. 1). Full irrigation application (I₁₀₀) was the application resulting the maximum yield for both varieties, followed by one full water-one restriction application I₁₀₀₋₇₀. Although the total amount of irrigation water given to the I₇₀ application with moderate water stress and one full water-one restriction application (intermittent water stress, IWS) I₁₀₀₋₄₀ applications was the same throughout the season, the yield values were in different statistical significance groups in both years. Significant decreases in yield were recorded in the applications with more severe water stress (I₄₀).

Water stress caused significant decreases in yield in both years. Since the rainfall in the second year of the experiment was higher than the first year and the air temperatures were more suitable for blackberries in September–October 2022, the yield values obtained in the second year were higher.

Table 3 Irrigation depth and evapotranspiration (ET)

Treatments		2021		2022	
Cultivars	Irrigation levels	Irrigation depth (mm)	ET (mm)	Irrigation depth (mm)	ET (mm)
‘Bursa II’ (C _B)	I ₁₀₀	418.7	537.2	497.6	571.8
	I ₁₀₀₋₇₀	365.4	493.8	428.4	508.8
	I ₇₀	309.3	450.0	357.3	444.0
	I ₁₀₀₋₄₀	312.2	449.4	359.2	443.2
	I ₄₀	199.9	351.9	217.1	322.6
‘Chester’ (C _C)	I ₁₀₀	327.0	444.8	404.4	481.2
	I ₁₀₀₋₇₀	284.3	408.9	349.8	433.4
	I ₇₀	239.7	376.7	292.1	382.5
	I ₁₀₀₋₄₀	241.7	374.7	295.1	382.8
	I ₄₀	152.4	297.3	179.8	289.7

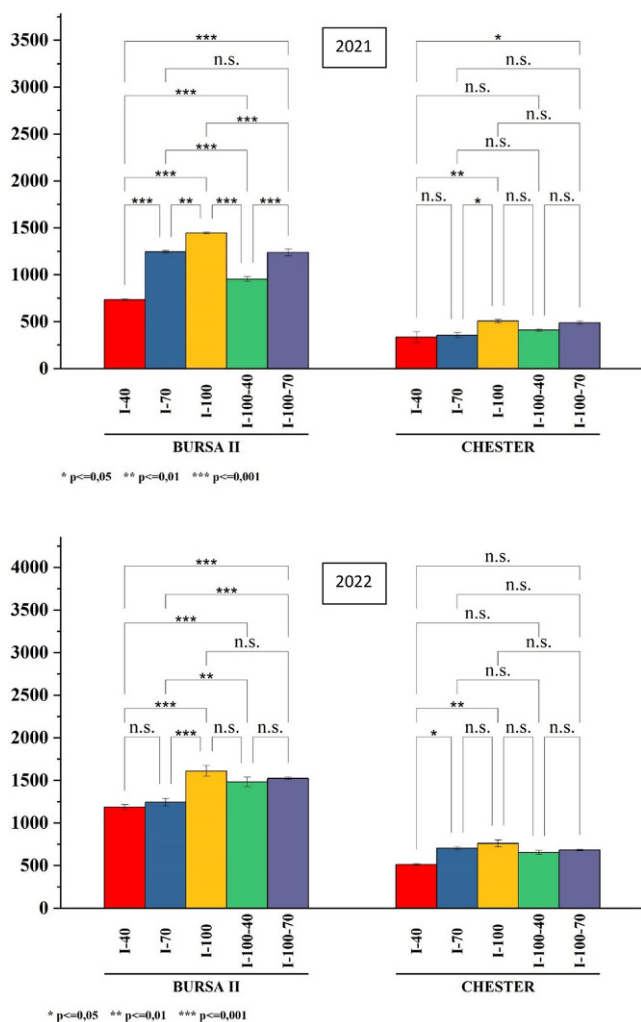


Fig. 1 Fruit yields (kg da^{-1}) of 'Bursa II' and 'Chester' varieties under different irrigation strategies

This situation can also be expressed as the plant being able to regulate its stress mechanism according to drought conditions. In a study conducted on different pruning lengths in blackberries, the highest yield was reported as 1113 kg da^{-1} in 'Bursa-4' variety (Gündüz et al. 2013). Again, in another study conducted on blackberries, it was stated that the highest yield was obtained from the 'Bursa II' variety according to 2-year cumulative yield values (Oruç and Oruç 2013). The yield values obtained are also increasing thanks to the determination of varieties compatible with the climatic conditions in Turkey and the more technical cultivation of blackberries, whose production area increases every year. While the Turkish average blackberry yield was 876.9 kg da^{-1} in 2021, it reached 986.5 kg da^{-1} in 2022 (TÜİK 2023). The main reason why these data are lower than the yield values obtained in our study is thought to be due to the application of programmed irrigation in the current study.

The results of variance analysis and mean values related to the effects of deficit irrigation applications on yield parameters are presented in Table 4. In the first year of the experiment, the values of fruit number, average fruit weight, shoot number per plant, average shoot length and average shoot diameter were found to be statistically significant. In other parameters except average shoot length, higher values were obtained in the 'Bursa II' variety. These results show that in arid and semi-arid climate conditions, full and deficit irrigation applications have more positive effects on yield parameters of the 'Bursa II' variety compared to the 'Chester' variety. While different irrigation levels were found to be effective on fruit number, average shoot length and shoot diameter values, they did not have an effect on average fruit weight and shoot number per plant parameters. Although some parameters were different among varieties in the second year of the experiment, irrigation level was evaluated as insignificant except for fruit number. Adult blackberry plants in bush form were not affected much by stress conditions in the second year of application.

In studies conducted on the adaptation and cultivation of different blackberry varieties under different climatic conditions, it was reported that the average fruit weight of 2.81 g was obtained from the 'Chester' variety (Altunbaş and Pırlak 2019) and the average fruit weight of 3.01 g was obtained from the 'Bursa 1' variety (Cangi and İslam 2003). The yield components of blackberry vary according to the maintenance conditions, shoot pruning lengths (Gündüz et al. 2013) and the adaptation of the variety to the region (Gruner and Kornilov 2020; Sabooni et al. 2022). When the proportional increase in vegetative development is high, the data obtained in pomological parameters may be lower. In the study, the increases in the shoot characteristics of the 'Chester' variety came to the fore, but smaller fruits were obtained compared to the literature (average fruit weight 2.17 g).

Determination of Fruit Characters

Table 5 presents the variance analysis results and average values for pH, TSS, and acidity of the fruit. The pH, TSS, and acidity readings, which are indicators of taste and fragrance characteristics, were considerably influenced by varying irrigation levels in both years when assessing the fruit's composition. The acidity levels varied across the different kinds in both years; nevertheless, there was no significant change in the pH and TSS values.

The pH values of different varieties in various regions of Turkey were as follows: 3.57 for the 'Chester' variety in Konya (Altunbaş and Pırlak 2019), 3.34 for the 'Jumbo' variety and 3.16 for the 'Chester' variety in Trabzon (İslam et al. 2009), and 3.15 for the 'Jumbo' variety in Tokat (Gerçekçioğlu et al. 2003). The research also yielded com-

Table 4 Agro-morphological parameters based on variety and irrigation levels

Years	Treatments	Fruit number (No./ plant)	Average fruit weight (g)	Shoot number per plant	Average shoot length (cm)	Average shoot diameter (mm)	
2021	<i>Cultivar (C)</i>						
	CB ('Bursa II')	3554 ^a	2.51 ^a	3.0 ^a	169.8 ^b	6.03 ^a	
	CC ('Chester')	1546 ^b	2.17 ^b	1.7 ^b	199.6 ^a	5.17 ^b	
	<i>Irrigation level (I)</i>						
	I100	2928 ^A	2.55	2.6	192.1 ^A	6.11 ^A	
	I100-70	2883 ^A	2.35	2.5	191.6 ^A	5.75 ^B	
	I70	2543 ^B	2.37	2.3	184.8 ^B	5.58 ^{BC}	
	I100-40	2406 ^B	2.29	2.4	189.3 ^A	5.45 ^C	
	I40	1990 ^C	2.11	2.1	165.7 ^C	5.14 ^D	
	<i>C x I (Interactions)</i>						
	CB	I100	4071 ^a	2.84	3.3	179.2 ^c	6.50
		I100-70	4011 ^a	2.47	3.1	179.1 ^c	6.28
		I70	3666 ^b	2.73	2.9	174.5 ^c	6.12
		I100-40	3412 ^c	2.24	3.0	175.2 ^c	5.79
		I40	2612 ^d	2.25	2.8	141.1 ^d	5.47
		CC	I100	1785 ^e	2.27	1.9	205.0 ^a
	I100-70		1755 ^e	2.23	1.9	204.0 ^a	5.21
	I70		1420 ^f	2.01	1.7	195.1 ^b	5.03
	I100-40		1401 ^f	2.35	1.8	203.5 ^a	5.11
	I40		1368 ^f	1.98	1.4	190.2 ^b	4.80
	<i>Significance</i>						
	Cultivar (C)	**	*	**	**	*	
	Irrigation level (I)	**	ns	ns	**	**	
	C x I	**	ns	ns	**	ns	
	2022	<i>Cultivar (C)</i>					
		CB ('Bursa II')	4380 ^A	2.58	3.3 ^A	163.1	7.32
		CC ('Chester')	2337 ^B	2.29	2.0 ^B	215.9	5.38
		<i>Irrigation level (I)</i>					
I100		3762 ^A	2.48	2.9	207.0	6.76	
I100-70		3472 ^{AB}	2.49	2.8	194.4	6.53	
I70		3220 ^{BC}	2.41	2.6	185.2	6.27	
I100-40		3502 ^{AB}	2.44	2.8	187.2	6.26	
I40		2838 ^C	2.37	2.4	173.8	5.92	
<i>C x I (Interactions)</i>							
CB		I100	4824	2.69	3.5	178.0	7.89
		I100-70	4575	2.66	3.5	167.3	7.61
		I70	4022	2.49	3.3	160.9	7.15
		I100-40	4634	2.60	3.5	166.4	7.26
		I40	3846	2.49	2.9	143.0	6.68
		CC	I100	2700	2.26	2.3	235.9
I100-70			2370	2.31	2.2	221.6	5.45
I70			2418	2.33	1.9	209.5	5.39
I100-40			2369	2.28	2.1	208.1	5.26
I40			1829	2.24	1.8	204.5	5.15
<i>Significance</i>							
Cultivar (C)		**	ns	*	ns	**	
Irrigation level (I)		**	ns	ns	ns	ns	
C x I		ns	ns	ns	ns	ns	

Lowercase letters, uppercase letters, and italics indicate Duncan groups for cultivar (C), irrigation level (I), and CxI interaction, respectively

ns Not significant

*, $P < 0.05$; **, $P < 0.01$

patible findings. The ‘Bursa II’ variety exhibited pH values ranging from 5.02 to 5.81 in the first year, and values ranging from 2.83 to 3.36 in the second year (Table 5). Noticeable elevations were seen in the titratable acidity measurements throughout the second year of the investigation. Due to the rise in acidity, there was a substantial fall in the pH values. This conclusion is supported by other investigations (Acosta-Montoya et al. 2010; Seraglio et al. 2018). In the first year, the ‘Chester’ (C_C) variety has an acidity level which is 33% greater than the ‘Bursa II’ (C_B) variety. Similarly in the second year, the ‘Chester’ variety has an acidity level that is 40% higher than the ‘Bursa II’ variety. However, when acidity levels are analyzed based on irrigation levels, it is evident that the acidity value falls as water stress intensifies for both varieties. The variability in acidity values is influenced by the genetic characteristics of the cultivars, irrigation rates, and changes in day and night temperatures. Based on the findings, Göktaş et al. (2006) documented that the ‘Jumbo’ variety had a titratable acidity level of 1.26%, while the ‘Chester’ variety had a level of 1.19%. Both in the first and second trial years, the TSS values were shown to be influenced by the irrigation

levels and the relationship between variety and irrigation level (Table 5). The I₄₀ individuals exposed to severe water stress had the largest dry matter quantity, although this value dropped when the irrigation level increased, as anticipated. The TSS values, which impact the fruit’s storage and transportation capabilities, ranged from 10.2 to 12.57% in the first year and from 9.47 to 16.23% in the second year. In arid and semi-arid climatic circumstances, the ‘Chester’ variety had a recorded TSS of 14.20% (Altunbaş and Pırlak 2019). However, in Giresun, which has a greater average rainfall, the ‘Chester’ variety had a reported TSS of 13.13% (Kurt et al. 2003). The TSS values of several blackberry cultivars were documented as follows: 6.67–8.00% (Schulz et al. 2019), 5.03–7.70% (Acosta-Montoya et al. 2010), and 8.07–10.97% (Threlfall et al. 2016). According to Fawole and Opara (2013), blackberries with high TSS levels and low acidity values result in sweeter fruits. As the fruits undergo ripening, their sweetness intensifies, and the TSS likewise proportionally increases.

Table 5 pH, acidity and total soluble solid (TSS) values in fruit content based on variety and irrigation levels

Treatments	pH		Total acidity (%)		TSS (%)		
	2021	2022	2021	2022	2021	2022	
<i>Cultivar (C)</i>							
C _B (‘Bursa II’)	5.55	3.06	0.738 ^B	0.930 ^B	11.13	12.79	
C _C (‘Chester’)	5.69	2.98	0.983 ^A	1.308 ^A	11.29	12.55	
<i>Irrigation level (I)</i>							
I ₁₀₀	5.38 ^C	2.91	0.930 ^A	1.641 ^A	10.48 ^D	10.57 ^E	
I _{100–70}	5.67 ^{AB}	2.95	0.914 ^{AB}	1.236 ^B	10.82 ^C	11.48 ^D	
I ₇₀	5.70 ^A	3.04	0.811 ^C	1.011 ^C	11.26 ^B	13.60 ^B	
I _{100–40}	5.63 ^B	3.02	0.850 ^{BC}	0.923 ^{CD}	11.32 ^B	12.50 ^C	
I ₄₀	5.71 ^A	3.18	0.800 ^C	0.785 ^D	12.17 ^A	15.18 ^A	
<i>C x I (Interactions)</i>							
C _B	I ₁₀₀	5.02 ^f	2.83	0.825	1.357	10.20 ^f	11.67 ^d
	I _{100–70}	5.62 ^{de}	2.97	0.821	1.033	10.67 ^e	12.33 ^{cd}
	I ₇₀	5.67 ^{cd}	3.06	0.667	0.772	11.15 ^d	13.03 ^c
	I _{100–40}	5.60 ^e	3.05	0.718	0.862	11.87 ^b	12.77 ^c
	I ₄₀	5.81 ^a	3.36	0.661	0.627	11.77 ^b	14.13 ^b
C _C	I ₁₀₀	5.75 ^b	2.98	1.035	1.924	10.77 ^e	9.47 ^f
	I _{100–70}	5.73 ^{bc}	2.93	1.007	1.438	10.97 ^d	10.63 ^e
	I ₇₀	5.73 ^{bc}	3.01	0.955	1.250	11.37 ^c	14.17 ^b
	I _{100–40}	5.67 ^{cde}	2.99	0.981	0.983	10.77 ^e	12.23 ^{cd}
	I ₄₀	5.61 ^{de}	3.00	0.938	0.943	12.57 ^a	16.23 ^a
<i>Significance</i>							
Cultivar (C)	ns	ns	**	*	ns	ns	
Irrigation level (I)	**	ns	**	**	**	**	
C x I	**	ns	ns	Ns	**	**	

Lowercase letters, uppercase letters, and italics indicate Duncan groups for cultivar (C), irrigation level (I), and CxI interaction, respectively
 ns Not significant

*, $P < 0.05$; **, $P < 0.01$

Table 6 Leaf area and some leaf physiological parameters based on cultivar and irrigation levels

Years	Treatments	Leaf area (cm ²)	Leaf temperature (°C)	SPAD	Stomatal conductance (mol m ⁻² s ⁻¹)	RLWC (%)	Membrane permeability (%)	
2021	<i>Cultivar (C)</i>							
	CB ('Bursa II')	56.03	27.8	82.42	263.3 ^b	57.50 ^a	15.77 ^a	
	CC ('Chester')	53.03	27.8	64.33	333.7 ^a	51.11 ^b	13.81 ^b	
	<i>Irrigation level (I)</i>							
	I100	56.34	27.0	89.33	327.0 ^A	64.73 ^A	11.91 ^C	
	I100-70	56.11	27.6	80.24	308.9 ^B	58.39 ^B	14.10 ^B	
	I70	53.77	28.2	66.40	276.9 ^C	54.70 ^C	15.40 ^B	
	I100-40	54.24	27.5	67.82	303.4 ^B	52.34 ^C	14.19 ^B	
	I40	52.17	28.9	63.07	276.3 ^C	41.36 ^D	18.34 ^A	
	<i>C x I (Interactions)</i>							
	CB	I100	57.82	27.1	99.31	315.9 ^c	63.94 ^a	13.17
		I100-70	57.51	27.8	83.91	278.9 ^d	64.07 ^a	15.18
		I70	55.51	28.3	77.91	227.3 ^f	57.94 ^b	15.75
		I100-40	55.82	27.5	79.20	268.5 ^e	52.05 ^c	15.32
		I40	53.47	28.5	71.77	226.1 ^f	49.51 ^c	19.43
	CC	I100	54.87	27.0	79.36	338.1 ^a	65.53 ^a	10.66
		I100-70	54.71	27.3	76.57	338.9 ^a	52.71 ^c	13.03
		I70	52.03	28.0	54.89	326.5 ^b	51.46 ^c	15.05
		I100-40	52.66	27.5	56.44	338.2 ^a	52.62 ^c	13.06
		I40	50.87	29.2	54.38	326.5 ^b	33.21 ^d	17.24
	<i>Significance</i>							
Cultivar (C)	ns	ns	ns	**	**	**		
Irrigation level (I)	ns	ns	ns	**	**	**		
C x I	ns	ns	ns	**	**	ns		
2022	<i>Cultivar (C)</i>							
	CB ('Bursa II')	38.93 ^a	29.4 ^a	81.23 ^b	332.7 ^b	42.56 ^a	16.09	
	CC ('Chester')	33.81 ^b	29.0 ^b	90.19 ^a	361.0 ^a	36.0b	14.67	
	<i>Irrigation level (I)</i>							
	I100	52.05 ^A	26.5 ^E	106.70 ^A	477.8 ^A	47.94 ^A	14.32	
	I100-70	41.43 ^B	27.5 ^D	99.45 ^B	393.6 ^B	43.92 ^A	17.10	
	I70	29.93 ^D	31.1 ^B	74.72 ^D	280.3 ^D	35.22 ^B	14.49	
	I100-40	35.75 ^C	28.5 ^C	90.27 ^C	336.4 ^C	39.43 ^B	14.57	
	I40	22.72 ^E	32.4 ^A	57.43 ^E	246.1 ^E	29.99 ^C	16.43	
	<i>C x I (Interactions)</i>							
	CB	I100	58.31 ^d	26.8 ^f	98.57 ^c	464.7 ^b	54.46 ^a	14.50
		I100-70	42.99 ^{bc}	27.7 ^e	91.10 ^e	384.3 ^d	49.05 ^b	17.24
		I70	31.89 ^{ef}	31.3 ^c	72.17 ^h	266.2 ^h	38.75 ^c	14.97
		I100-40	35.93 ^{de}	28.4 ^d	86.17 ^f	311.1 ^f	41.51 ^c	14.89
		I40	25.54 ^g	32.9 ^a	58.17 ^t	237.0 ⁱ	29.05 ^d	18.86
	CC	I100	45.79 ^b	26.2 ^g	114.83 ^a	491.0 ^a	41.41 ^c	14.14
		I100-70	39.86 ^{cd}	27.4 ^e	107.80 ^b	402.8 ^c	38.80 ^c	16.96
		I70	27.96 ^{fg}	30.9 ^c	77.27 ^g	294.3 ^g	31.70 ^d	14.00
		I100-40	35.57 ^{de}	28.5 ^d	94.37 ^d	361.7 ^e	37.34 ^c	14.24
		I40	19.89 ^h	31.9 ^b	56.70 ^t	255.1 ^t	30.93 ^d	14.00
	<i>Significance</i>							
Cultivar (C)	*	*	**	**	*	ns		
Irrigation level (I)	**	**	**	**	**	ns		
C x I	**	*	**	**	**	ns		

Lowercase letters, uppercase letters, and italics indicate Duncan groups for cultivar (C), irrigation level (I), and CxI interaction, respectively

ns Not significant, RLWC Relative leaf water content

*, P < 0.05; **, P < 0.01

Determination of Physiological Parameters

In the first year of the experiment, there was no significant difference between the measured leaf areas according to irrigation levels and varieties, while the data obtained in the second year were found to be statistically significant. Except for C_BI₁₀₀, it was observed that the leaf areas of other applications decreased significantly (Table 6). As a result of the effect of the deficit irrigation applications in the first year, the plants adapted to stress in the second year of the experiment, and therefore had smaller leaves.

The difference between the leaf temperatures was insignificant in the first year, but significant in the second year, according to the effect of the varieties and irrigation levels (Table 6). Maintaining the optimum plant temperature is very important for the metabolic activities of a plant, and this balance is regulated by transpiration (Bahuguna and Jagadish 2015; Zandalinas et al. 2016; Dusenge et al. 2019). Transpiration removes the latent heat of evaporation and thus cools the leaf surface (Lin et al. 2017). In the absence of soil moisture, i.e. under stress conditions,

the transpiration rate decreases and the leaf temperature increases (Schoppach and Sadok 2012). In the research, as water stress increased, leaf temperature values also increased.

While the difference between SPAD measurements in the first year was found to be insignificant, the effect of varieties and water stress applications on SPAD values in the second year was found to be significant (Table 6). According to SPAD measurements, the highest values were obtained under full irrigation conditions, while a decrease of more than 40% was observed as water stress increased. SPAD value is a numerical value obtained as a result of measurement according to the intensity of green color in leaves and is used to determine leaf chlorophyll content (Dey et al. 2016). It is important in providing information about chlorophyll and photosynthesis status especially under water stress conditions (Ahmed et al. 2010) and determining the threshold stress level of the plant. While almost the same average SPAD value was measured in both experimental years in the ‘Bursa II’ variety (82.42, 81.23), there was a 40% increase in the ‘Chester’ variety compared

Table 7 Leaf biochemical characteristics based on cultivar and irrigation levels

Treatments	Proline content (mg g ⁻¹ FW)		H ₂ O ₂ content (mmol kg ⁻¹ FT)		Malondialdehyde content (EU g ⁻¹ FT)		
	2021	2022	2021	2022	2021	2022	
<i>Cultivar (C)</i>							
C _B (‘Bursa II’)	0.131 ^b	0.148 ^b	31.00 ^a	34.24 ^a	15.80 ^a	17.61 ^a	
C _C (‘Chester’)	0.306 ^a	0.346 ^a	16.20 ^b	18.25 ^b	9.00 ^b	10.96 ^b	
<i>Irrigation level (I)</i>							
I ₁₀₀	0.125 ^D	0.139 ^D	17.77 ^E	20.50 ^E	7.85 ^E	9.10 ^E	
I ₁₀₀₋₇₀	0.140 ^D	0.156 ^D	20.57 ^D	22.25 ^D	10.30 ^D	11.93 ^D	
I ₇₀	0.198 ^B	0.230 ^B	25.06 ^B	28.14 ^B	13.90 ^B	15.95 ^B	
I ₁₀₀₋₄₀	0.170 ^C	0.195 ^C	22.82 ^C	24.62 ^C	12.86 ^C	14.83 ^C	
I ₄₀	0.460 ^A	0.514 ^A	31.78 ^A	35.69 ^A	17.09 ^A	19.63 ^A	
<i>C x I (Interactions)</i>							
C _B	I ₁₀₀	0.044 ^f	0.050 ^f	22.02 ^e	25.41 ^e	8.72 ^{fg}	9.51 ^g
	I ₁₀₀₋₇₀	0.053 ^f	0.059 ^f	25.67 ^d	27.36 ^d	12.57 ^d	14.49 ^d
	I ₇₀	0.078 ^f	0.089 ^f	33.06 ^b	36.57 ^b	18.16 ^b	20.02 ^b
	I ₁₀₀₋₄₀	0.070 ^f	0.078 ^f	28.87 ^c	31.43 ^c	16.94 ^c	19.36 ^c
	I ₄₀	0.411 ^b	0.464 ^b	45.35 ^a	50.40 ^a	22.60 ^a	24.68 ^a
C _C	I ₁₀₀	0.206 ^e	0.229 ^e	13.51 ⁱ	15.59 ⁱ	6.97 ^h	8.68 ^h
	I ₁₀₀₋₇₀	0.228 ^e	0.253 ^e	15.47 ^h	17.14 ⁱ	8.04 ^g	9.37 ^g
	I ₇₀	0.318 ^c	0.371 ^c	17.06 ^g	19.71 ^g	9.64 ^f	11.87 ^e
	I ₁₀₀₋₄₀	0.271 ^d	0.312 ^d	16.76 ^g	17.80 ^h	8.77 ^{fg}	10.30 ^f
	I ₄₀	0.508 ^a	0.564 ^a	18.20 ^f	20.98 ^f	11.59 ^e	14.58 ^d
<i>Significance</i>							
Cultivar (C)	**	**	**	**	**	**	
Irrigation level (I)	**	**	**	**	**	**	
C x I	**	**	**	**	**	**	

Lowercase letters, uppercase letters, and italics indicate Duncan groups for cultivar (C), irrigation level (I), and CxI interaction, respectively
ns Not significant

*, $P < 0.05$; **, $P < 0.01$

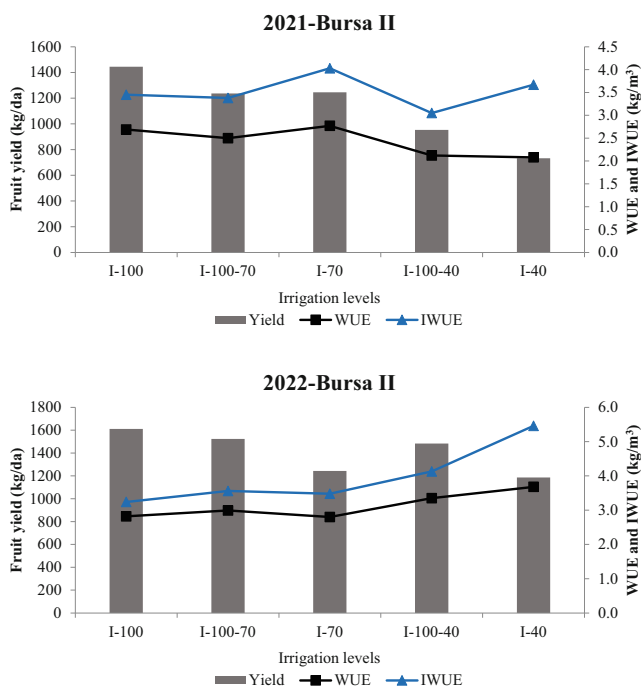


Fig. 2 Water use efficiency (WUE) and irrigation water use efficiency (IWUE) values of the ‘Bursa II’ variety

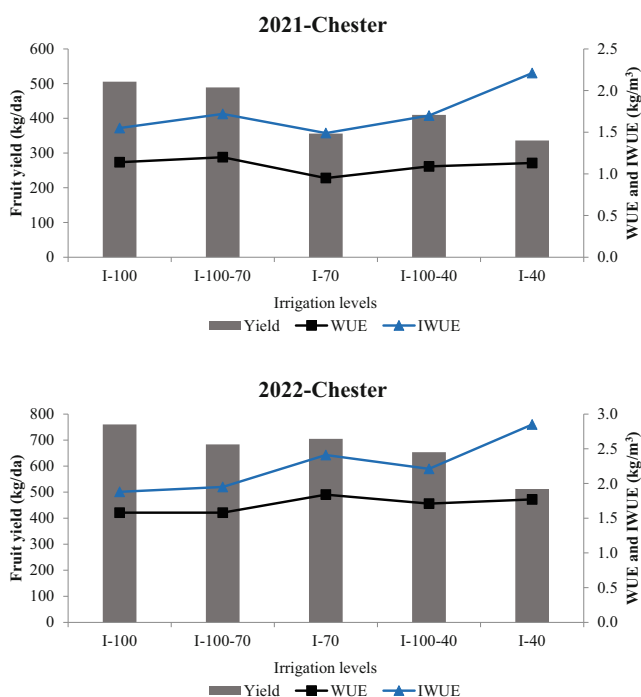


Fig. 3 Water use efficiency (WUE) and irrigation water use efficiency (IWUE) values of the ‘Chester’ variety

to the first year. Accordingly, it can be said that the ‘Chester’ variety adapted to stress and balanced the amount of chlorophyll and net photosynthesis.

When the difference between the varieties is examined, it was observed that stomatal conductance was higher in the ‘Chester’ variety in both years and that increasing water stress decreased stomatal conductance (Table 6). Under water stress conditions, plants try to avoid drought by closing their stomata and as a result, stomatal conductance decreases (Singh and Reddy 2011; Zhou et al. 2013). It has been reported that species adapted to drought avoid drought by closing their stomata under water stress conditions and thus reach higher yields (Yavuz et al. 2024). In the present study, it was observed that the ‘Bursa II’ variety, which obtained higher yields compared to the ‘Chester’ variety under both full and deficit irrigation conditions, balanced water loss through its stomata.

In both years, LRWC values were significantly affected by water stress. The highest LRWC values were measured in the first year as 65.53% and in the second year as 54.46% in fully irrigated treatments (Table 6). In the severe water stress treatment (I40), a decrease of 50% was observed. LRWC is an indicator of water balance in the plant and is an important indicator in determining the plant’s water stress tolerance (Teulat et al. 2003). In our study, the decreases in LRWC indicate that the effect of osmotic stress caused by water stress has increased and the plant has difficulty in maintaining its water balance.

Membrane damage values were found to be significant in terms of varieties and irrigation levels in the first year, while the differences between the treatments were found to be insignificant in the second year (Table 6). The highest membrane damage (18.34) was found in the I₄₀ treatment with 60% stress, while the lowest membrane damage (11.91) was found in the fully irrigated I₁₀₀ treatment. Moreover, no statistically significant difference was found in membrane damage among the I₁₀₀₋₇₀, I₇₀ and I₁₀₀₋₄₀ treatments. In other words, it was observed that membrane integrity could be preserved in the treatments with 30% water stress (I₇₀ and I₁₀₀₋₄₀) compared to the treatment with 15% water restriction (I₁₀₀₋₇₀). Plants affected by different irrigation levels in the first year adapted to water stress conditions in the second trial year. Thus, the different irrigation level applications did not show a statistically significant effect on membrane damage in the second year. Similar to our findings, the highest membrane damage was found in treatments subjected to severe water stress in spinach (Seymen 2021) and lettuce (Yavuz et al. 2021). In studies conducted on blackberry, it has been reported that abiotic stresses increase membrane damage (Arıkan et al. 2018; İpek et al. 2018).

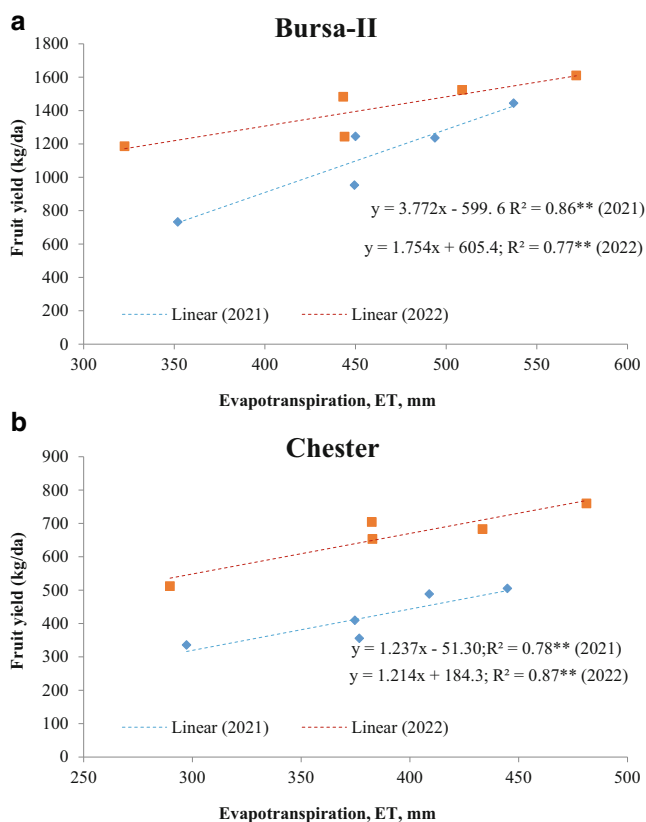


Fig. 4 Relationships between yield and evapotranspiration (ET) for 'Bursa II' (a) and 'Chester' (b)

Determination of Biochemical Parameters

The results of variance analysis and mean values related to proline, H_2O_2 and MDA contents are given in Table 7. While the effects of different water stress applications on proline contents were found to be significant, the average proline content measured in the 'Chester' variety was found to be 133% higher than the average proline content of the 'Bursa II' variety. It is known that as the stress rate applied to plants increases, they synthesize proline and this value increases in direct proportion to the stress intensity. However, in this study, although the stress level was different, the proline contents measured in I_{70} and I_{100-40} treatments applied with equal irrigation water were found to be different. Higher proline synthesis occurred in I_{70} treatment compared to I_{100-40} treatment, in other words, it was observed that I_{70} treatment applied with constant water stress experienced more water stress. These results showed that with periodic restriction application (I_{100-40}), plants would be less affected by water stress.

The applications made in the study have a statistically significant effect on H_2O_2 values. Increased water stress caused an increase in compounds that cause oxidative damage such as H_2O_2 . The difference between the varieties is

related to the characteristics of the varieties themselves; however, it can be explained by the lower fruit load of the 'Chester' variety, which has fewer yields. H_2O_2 , one of the biochemical measures of stress, was measured nearly 50% less in the 'Chester' variety.

Damage to cell membrane fatty acids in plants (Chiaperro et al. 2019) causes the production of hydrocarbons such as MDA, which is an important indicator of membrane damage, and increases oxidative damage (Perveen et al. 2013; Yavuz et al. 2022). In the study, MDA values vary significantly according to both variety differences and irrigation levels. The highest value was seen in I_{40} applications, which was a severe stress application in both years. In these applications, more than 100% more damage occurred compared to the fully irrigated treatment. When we look at I_{70} and I_{100-40} applications, it is seen that less MDA occurs in IWS. This shows that IWS have a positive effect in reducing the stress level of the plant.

WUE, IWUE and Yield Response Factor (Ky)

WUE and IWUE values, which are important indicators in comparing different irrigation strategies, are given separately for both varieties in Figs. 2 and 3, respectively. In the first year of the experiment, the highest WUE was calculated in the I_{70} application of the 'Bursa II' variety with 2.77 kg m^{-3} . This treatment was followed by I_{100} , I_{100-70} , I_{100-40} and I_{40} treatments, respectively. In the 'Chester' variety, the highest WUE in the first year was calculated in the I_{100-70} with 1.20 kg m^{-3} . In the second year of the experiment, with the increase in yield values, WUE values also increased in all treatments.

When the IWUE results are examined, we can see that the highest value was calculated in the 'Bursa II' variety. Among the different irrigation strategies, the highest IWUE values were calculated in the I_{70} application with 4.03 kg m^{-3} in 2021 and in the I_{40} application with 5.46 kg m^{-3} in 2022. The increase in fruit yield in both trial years was reflected in the WUE and IWUE values. However, while the highest WUE and IWUE values were obtained in the I_{70} treatments, which were applied moderate water stress in the first year, the highest values were reached in the I_{40} treatments, which were applied severe water stress in the second year. The reason for this is thought to be related to the increase in adaptation of blackberry, a perennial plant in the form of a bush, to stress conditions. In a study conducted in a region with different climate characteristics, the WUEs of 'Bursa I' and 'Chester' varieties were calculated as 1.14 kg m^{-3} and 0.93 kg m^{-3} , respectively, and their IWUEs were calculated as 1.26 kg m^{-3} and 1.02 kg m^{-3} , respectively (Sakar Erdogan 2019).

In this study, yield response factors (ky) were determined in order to determine the effect of the decrease in evapo-

Fig. 5 Yield response factors (ky) for ‘Bursa II’

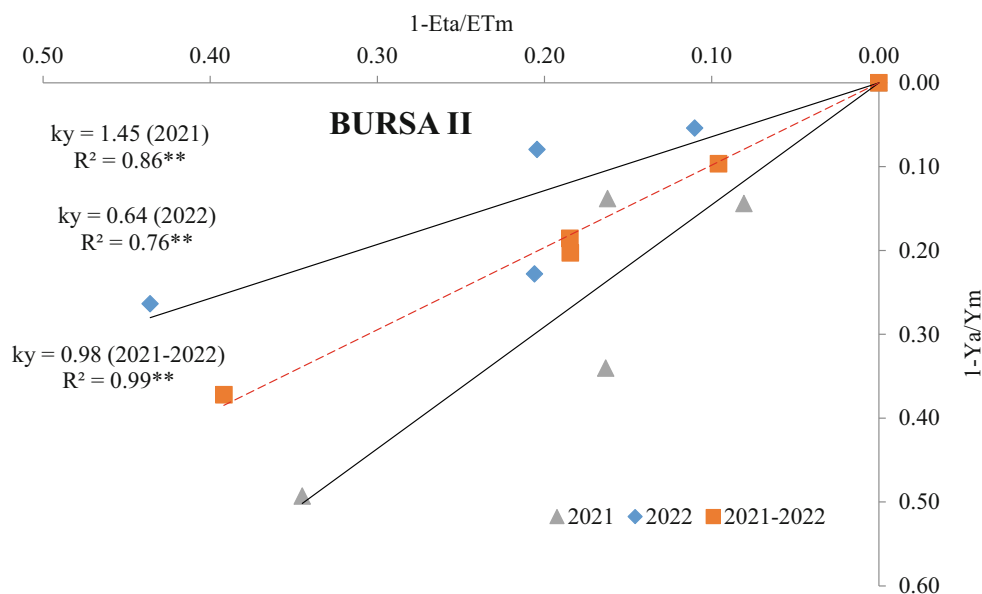
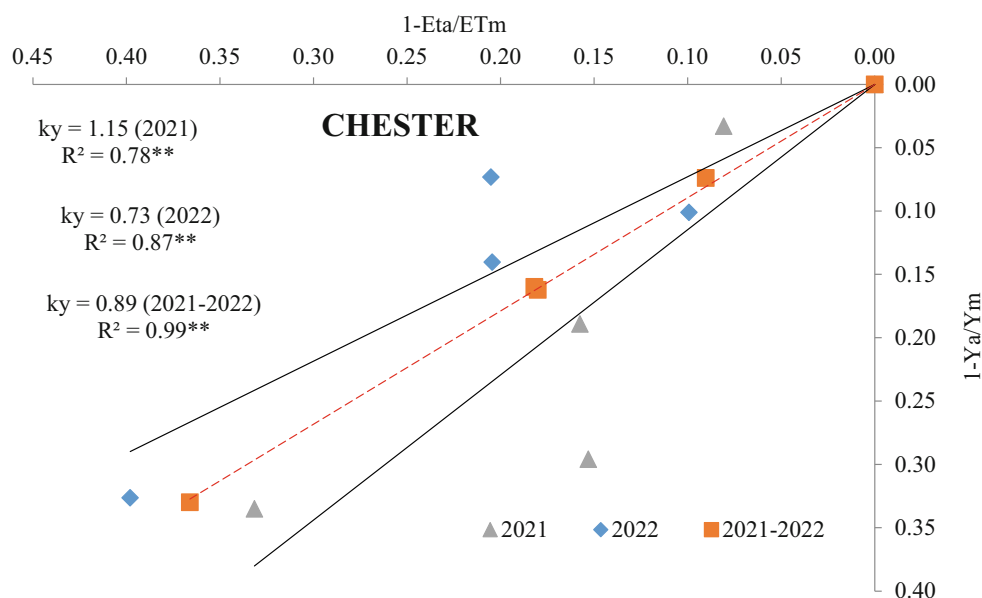


Fig. 6 Yield response factors (ky) for ‘Chester’



transpiration (ET) on the decrease in fruit yield. For this purpose, the relationships between ET and fruit yield values in two different blackberry cultivars were examined using regression analyses (Fig. 4). As a result of the analyses, strong linear relationships were found between ET and fruit yield at a significance level of 1%. In this study, the results of ky values calculated separately for both trial years are given in Figs. 5 and 6. In the first year of the trial (2021), ky was calculated as 1.45 and 1.15 for ‘Bursa II’ and ‘Chester’, respectively. These results show that both varieties could not adapt to stress conditions in 2021. On the other hand, ky was calculated less than 1.00 for both varieties in 2022. In other words, it was observed that blackberry adapted to water stress in 2022 and there were no significant decreases in yield under deficit irrigation. Studies on

water–yield relationships of blackberry are almost non-existent. Doorenbos and Kassam (1979) stated that when $ky > 1$, the plant is sensitive to water deficit, and when $ky < 1$, the plant is tolerant to water stress. As a result, the current study has yielded data indicating that the sensitivity of blackberry, a perennial plant, to water deficit may decrease and that the plant can adapt to stress conditions over time.

Conclusion

This study was conducted to determine the effects of full and deficit irrigation on yield, morphological and some biochemical properties of blackberry. The ‘Bursa II’ variety, compared to the ‘Chester’ variety, showed a higher adap-

tation to the regional climate conditions and stood out in terms of fruit yield and quality parameters (fruit number, fruit weight) and morphological measurements (shoot number, shoot length, shoot diameter, leaf area, etc.). As a result of the research, plant water consumption of blackberry plant under different irrigation strategies in arid and semi-arid conditions was determined. The highest water consumption value of blackberry was calculated as 571.8 mm in 2022 in the fully irrigated treatment of the ‘Bursa II’ variety. For the ‘Chester’ variety, this value calculated in the same year in the fully irrigated treatment was 481.2 mm. These values determined in field conditions showed that blackberry can be a good alternative to plants that consume a lot of water for arid and semi-arid regions. According to irrigation levels, the amount of compounds that are indicators of oxidative damage such as H₂O₂ and malondialdehyde increased in parallel with the increase in stress conditions. However, a different deficit irrigation strategy, namely one periodic full irrigation–one deficit irrigation application, produced better results than the treatments with regular water deficit in some important parameters. This showed that the intermittent water stress method can be applied in regions with limited water resources to save irrigation water without increasing the stress level of the plant.

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Author Contribution Nurcan Yavuz: Writing—Original draft, Methodology, Investigation, Formal analysis, Data curation, Validation. Muzaffer İpek: Original draft, Data curation, Methodology, Investigation. Şeyma Arıkan: Original draft, Data curation, Investigation. Duran Yavuz: Methodology, Investigation. Merve Karakoyun: Data curation, Investigation

Conflict of interest N. Yavuz, M. İpek, Ş. Arıkan, D. Yavuz and M. Karakoyun declare that they have no competing interests.

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