

Evaluation of the yield of strawberry genotypes by morpho-physiological parameters under deficit irrigation in the Mediterranean environment

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Abstract

The most pressing concern of the century is food security, mostly supported by irrigated agriculture. In this respect, studies on water stress have drawn increased attention with a highlighting expectation foreseen via our breeding efforts documented in this study concerning the significant commercial strawberry cultivars 'Rubygem', 'Sabrina' and 'Festival' along with some selected superior bred lines ('33', '36', '59', '61' and '112'). Plants cultivated in the Spanish-type high tunnel were exposed to both full (IR100) and deficit irrigation (IR50) in the Mediterranean part of Türkiye. Fruit yield as well as certain critical morphological and physiological parameters were examined throughout the active harvest period. This study found that the parameters relating to the vegetative components, as well as the fruit weight and yield, drastically dropped when plants were subjected to deficit irrigation. Therefore, depending on the limited irrigation, as a result of the closure of stomata, it was concluded that the amount of water and stomatal conductance of the plant is associated with a decrease. IR50 was found to have less impact on low-yield genotypes than on high-yield genotypes. Photosynthetic activity and stomatal conductivity were high in the '33' bred line with a high yield. On the other hand, photosynthesis activity and leaf water potential (LWP) values were relatively low in the '36' bred line with low yield. The study proved that variables like photosynthetic activity, stomatal conductance, and LWP could be used as markers for high yield genotype selection.

Keywords: bred lines; leaf water potential; Mediterranean climate; photosynthesis; stomatal conductivity

Introduction

Water pollution, climate change, population increase, and expanding industry are all recognized to be causing a progressive decline in the amount of water available for agriculture. In addition, UNESCO research states that water scarcity currently affects one-third of the world's population and is predicted to affect two-thirds of people by 2025 (UNESCO, 2009). Therefore, it is envisaged that agricultural transpiration rates

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would rise over the following ten years (Houghton *et al.*, 2001; European Environment Agency, 2004), increasing crop water requirements. Hence, under present and potential future situations, evaluating alternative irrigation regimes and increasingly popular sustainable agriculture studies such as genotype resistance to drought, could help to achieve optimal production and yield quality. In this respect, because of its remarkable adaptability and response to the changing available water conditions, the strawberry is one of the most extensively grown and popular variety of berry fruit (Ağaoğlu and Gerçekçiolu, 2013). Nevertheless, there is a shortage of information regarding the yield and fruit quality responses of strawberry species to drought, despite research accomplished on strawberry growing at various irrigation levels (Kapur *et al.*, 2022).

Fragaria chiloensis was shown to be more drought resistant than *F. virginiana* and *F. × ananassa* among strawberry species (Zhang and Archbold, 1993). Due to its thick leaves and cuticles (Zhang and Archbold, 1993), relatively sunken stomata, and reduced stomatal area of each leaf, this species offers better osmotic management than other *Fragaria* species (Darrow and Dewey, 1934; Hanninen *et al.*, 1999).

Additionally, the South American *F. chiloensis* line ‘Manzanar Alto’ had similar transpiration levels to commercially cultivated strawberries, however North American *F. chiloensis* types required significantly less water than *F. × ananassa* (Grant *et al.*, 2012). Under limited irrigation conditions, significant reductions in new leaf production, stomatal conductivity, and photosynthesis were detected, though at varying amounts among genotypes. Ginè Bordonaba and Terry (2010) reported that the responses of strawberry genotypes to water stress are different and that the dry matter content increased dramatically, resulting in a significant reduction in fruit size in several cultivars. Moreover, they indicated that reduced irrigation between flowering and harvesting boosted the flavour components in the ‘Elsanta’, ‘Sonata’, and ‘Symphony’ cultivars but had no influence on fruit size in some cultivars (‘Christine’ and ‘Florence’). ‘Elsanta’ strawberry produced under low irrigation conditions had much higher abscisic acid levels than sufficiently irrigated crops (Terry *et al.*, 2007), and the dry matter content of the same plants increased by 25% with limited irrigation. Limited irrigation applied to the fruits in the early stage has been observed to result in a significant reduction (1.7 times) in fruit size by Kapur *et al.* (2018b), who also investigated the effects of different irrigation regimes (IR50, IR75, IR100 and IR125) on yield and some physiological parameters. The yield decreased dramatically at the IR50 irrigation level, whereas the ‘Rubygem’ cultivar’s response was similar at other irrigation levels. It was statistically in the same group in terms of yield, whereas, stomatal conductivity and leaf water potential dramatically decreased as the irrigation level was decreased in the same study.

When observing prior studies, it is obvious that the amount of water provided to strawberry species and even variants within the species produces variable results regarding physiological, yield, and fruit quality characteristics. Considering that the demand for irrigation water is growing daily, we must produce genotypes with high water use efficiency for each fruit species. In this context, it would be critical to compare specially bred strawberry genotypes with commercial varieties and reveal how they respond to less irrigation and, consequently, their effect on strawberry cultivation. Therefore, the aims of this research were (1) to compare the advanced selected genotypes with commercially grown strawberry cultivars in terms of yield, (2) to determine the least affected genotype(s) under the climatic conditions of a Mediterranean deficit irrigation regime during the active harvest season, and (3) to evaluate the combined effect of these factors (genotype × irrigation regime) by using morphologic and physiological parameters.

Materials and Methods

Experimental field

The study was conducted in the experimental field of the Department of Horticultural Science, Faculty of Agriculture, Çukurova University, during the 2019-2020 growing season. The trial area is located in Adana, Turkey, at latitude 36°59' N and longitude 35°18' E, and the average height of the trial area from the sea level

is 40 m. Adana's climate is Mediterranean, with mild and rainy winters and hot and dry summers. The soils at the site have been identified as clay-textured Xerofluvents of the Entisol order (Dingil *et al.*, 2010). The pH of the top 0.3 m's dry soil was 7.6, and its bulk density ranged from 1.33 to 1.41 g cm⁻³. The soil water content at field capacity and the permanent wilting points were 36.3 g g⁻¹ and 15.7 g g⁻¹, respectively.

Strawberry cultivar and genotypes characteristics

'Sabrina': It is a short-day cultivar. This cultivar's smooth and conical-shaped, firm, and huge fruits are resistant to transportation. It has a strong aroma and a hard texture. It matures early and shows rapid coloration despite low temperatures. Tolerant to calyx blight.

'Rubygem': It is a short-day cultivar. It is an early cultivar with a good taste and aroma and softer fruit flesh than Festival. This cultivar with bright red colour and huge fruit is susceptible to powdery mildew disease and tolerant to Fusarium wilt. It is a popular cultivar grown in Türkiye for domestic and export markets.

'Festival': It has a conical fruit shape with light red flesh and a dark and bright crimson exterior hue. It is an early cultivar. In terms of fruit quality, yield, and shelf life, it is quite comparable to 'Camarosa'.

'33': This genotype was hybrid by crossing 'Fortuna' × 'Kaşka' cultivars and has a regular form in the early phase and maintains the fruit shape throughout the season. The '33' bred line is renowned for its dark red fruits, high production capacity, and its large amount of harvest in June that meets the production gap between the highland and coastal locations. Significant fungal diseases were not visually observed in this genotype with sparse leafing (Sarıdaş, 2018).

'36': This genotype, which produces well-shaped and prominent fruits as well as its small plant structure, was obtained from the hybridization of 'Fortuna' × 'Kaşka' varieties. The fruits of this genotype are light red and have a unique aroma. Furthermore, the fruit shape is maintained throughout the season, with 750-900 g/plant production (Sarıdaş, 2018).

'59': The 'Fortuna' × 'Sevgi' cultivars were crossed to produce this genotype with moderate plant growth. This bred line stands out for its high yield, especially in May and June, as well as its consistent crop production throughout the season. It is an important genitor with its bright red, aromatic, and good fruit shape (Sarıdaş, 2018).

'61': This genotype with a strong plant structure was obtained by crossing 'Fortuna' × 'Sevgi' cultivars. This bred line has very large, well-shaped fruits and high yields. Its long pedicel size provides an advantage to fruit set and development (Sarıdaş, 2018).

'112': Its limited branching allows flower development and pollination of growing blooms in addition to its strong plant structure. This genotype was obtained by crossing 'Fortuna' × 'Sevgi' cultivars. Delicious and perfectly shaped fruits are produced by the genotype that maintains its huge, long conical fruit shape throughout the season (Sarıdaş, 2018) (Figure 1).

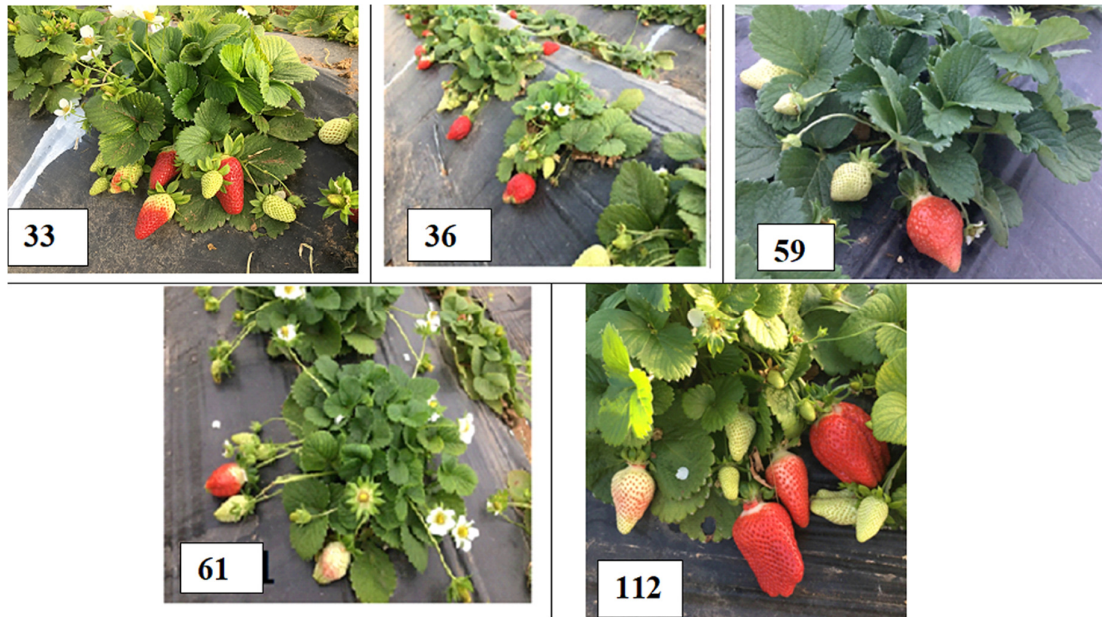


Figure 1. Plant and fruit of bred lines

Growing conditions and soil preparation for strawberries

The plants were cultivated in a Spanish-style high tunnel of about 6.5 meters wide, 2.75 meters high, and 40 meters long, with UV, IR, AB, EVA, and LD additive plastic with a 36-month lifetime.

The ridges were formed on the field to be planted after the soil was prepared by deep plowing and levelling. The ridges were arranged in such a way that the width of the ridge was 65-70 cm, the height was 35 cm and the distance between the two ridges was 35-40 cm. After irrigation, the prepared ridges were covered with 20 micron thick black-coloured polyethylene mulch material. Strawberry cultivars were planted in double rows in a triangle pattern on the ridges at 30 cm intervals.

Irrigation regimes and experimental design

The two irrigation treatments with applied water amounts of 0.5 and 1.00 times the pan evaporation (E_p) was designated as IR50 and IR100. The experiment was set up in a randomized block design with four replications according to the time-repetitive split-plot design. Each replication consisted of 30 plants, with the main plots divided into two irrigation regimes and varieties placed on the sub-plots. Fruit analyses and plant physiological measurements were conducted during the active harvest periods in March, April, and May.

Amount of water applied

The drip irrigation system consists of a fertilizer tank, main pipe, water distribution pipes (Lateral), and drippers. Laterals are black, flexible polyethylene pipes with a 16.00 mm diameter. Irrigation water is conveyed to the parcel via a Ø 50 PVC main pipeline and a dripper with a flow rate of 4 l/h with 30 cm intervals on the lateral line laid between two rows of plants on the ridge. The plants were supplied with lifeline water after planting in the high tunnel. Furthermore, all plants in the experiment were irrigated with 138.23 mm of irrigation water until they developed trifoliate leaves to adapt the seedlings to the growing conditions (November 8, 2019), followed by two more irrigation levels implemented after this date. The irrigation water was calculated using evaporation measurements derived from a Class A evaporation pan. Crop pan coefficients were selected as 0.5 for IR50 and 1 for IR100 applications. The following calculation was used to calculate the water required for irrigation (Eq. 1).

$$IR: E_{pan} \times P \times K_{cp} \tag{1}$$

IR: Amount of irrigation water (mm)

E_{pan} : Class A pan evaporation (mm)

K_{cp} : Crop pan coefficient

P: Wetted area (%)

Irrigation Water Use Efficiency (IWUE)

Howell *et al.* (1995) utilized the equation for irrigation water use efficiency.

$$IWUE = \frac{E_y}{IR}$$

(2)

IWUE: Irrigation water use efficiency (g/mm/plant)

E_y : Yield (g plant⁻¹)

I: Total amount of irrigation water applied (mm)

Yield per plant (g plant⁻¹)

The weights of fruits obtained from the plot were weighed on a scale sensitive to 0.1 g during the harvest season, and the yield per plant was determined by dividing this value by 30 for the number of plants in each plot.

Morpho-physiological measurements

The following physiological parameters were measured during the effective strawberry harvesting months of March, April, and May.

Leaf area (cm² plant⁻¹)

Leaf area (LAI) was measured monthly using LICOR LAI-3100. The acquired values were used to compute the leaf area per plant.

Net photosynthesis rate (mol CO₂ m⁻²s⁻¹) and stomatal conductance (μmol m⁻²s⁻¹)

The Net Photosynthesis rate (Pn) and stomatal conductance (gs) are eco-physiological measures that provide information concerning the plant stress condition under deficit irrigation. To monitor the internal water status of the plants, the net photosynthesis rate and stomatal conductance measurements were carried out with the leaf CI-340 photosynthesis meter at noon (11:00-13:00) on leaves that were completely sun-facing and newly developed from 3 plants from each plot.

Leaf water potential (bar)

The leaf water potential was measured with a portable pressure chamber device PMS Instrument Company (Model 615) at midday (between 12:00 and 13:30) from three plants from each plot. In each repetition, measurements were taken on three fully developed, sun-facing leaves, and the average was used to calculate the mid-day leaf water potential value.

Statistical analysis

The JMP 8.1 statistical package program based on SAS was used to evaluate the data obtained. The results were compared with the LSD test at the 5% significance level. In addition, the XL stat program was used to determine the correlations between the parameters and factor combinations.

Results and Discussion

Irrigation amounts (mm)

Cultivar and bred lines were planted in the high tunnel on September 18, 2019, and watered only with 138.23 mm irrigation water until they developed three trifoliolate leaves. Following this period, different irrigation levels, namely IR100 (727.13 mm) and IR 50 (432.72 mm), were applied 38 more times during plant development.

Choosing the optimal amount of irrigation water for strawberry species sensitive to water stress due to their shallow root structures is one of the most challenging strawberry production aspects. From 250 mm to 825 mm of irrigation water were applied in previous trials of drip irrigation in strawberry production (Lozano *et al.*, 2016; Kumar and Dey, 2011; Strand, 2008; Trout and Gartung, 2004; Yuan *et al.*, 2004; Kanber *et al.*, 1986). With a range of 564 to 795 mm of seasonal irrigation water, the strawberries in the Huelva region of Spain produce between 1027 and 1084 g of yield per plant (Lozano *et al.*, 2016). McNiesh *et al.* (1985) report strawberry yields of 20 to 50 t ha⁻¹ at the Californian coast obtained by 300 to 700 mm of irrigation water per year. Studies conducted in Bulgaria revealed that 700 to 800 mm of irrigation water was required for the highest strawberry production (Ivanov, 1977).

In contrast, this amount was 336 mm in Japan (Yuan *et al.*, 2004) and 485 mm in Italy (Giovanardi and Testolin, 1984). As inferred from earlier research, soil structure is a key element in estimating irrigation water in addition to direct factors such as the meteorological conditions of the strawberry growth area, the irrigation management method, planting time, and the genotype grown. In this context, our previous studies conducted under Mediterranean conditions bear a significant role in Turkish strawberry production, revealing the use of 274 mm (Kapur *et al.*, 2018b) and 397 mm of irrigation water required for optimal yields (Sarıdaş *et al.*, 2021a) obtained on clayey soils that highly depend on climatic conditions, planting time, and the length of the growing season. Yuan *et al.* (2004) determined that, depending on the temperature, the daily plant water consumption was lower in the early period (4 December - 20 March) but increased significantly in the latter (21 March - 20 June), revealing the increase of the irrigation water demand by rising temperatures.

Irrigation Water Use Efficiency (g mm⁻¹plant⁻¹)

We determined that as irrigation water decreased, irrigation water use efficiency increased significantly, from 1.42 g mm⁻¹plant⁻¹ for IR 50 to 1.18 g mm⁻¹plant⁻¹ for IR 100 (Table 1). Similarly, statistically significant differences were also detected in the irrigation water use efficiencies of the studied genotypes. In this respect, the highest IWUE was determined in the commercial cultivar 'Sabrina' (1.60 g mm⁻¹plant⁻¹), statistically followed by '59' and '33' bred lines (1.50 and 1.36 g mm⁻¹plant⁻¹) in the same group. The lowest water use efficiency was obtained in genotype '36' with a 0.95 g mm⁻¹plant⁻¹. The genotype × irrigation regime interaction was found statistically insignificant in the study. In this context, it was found that, except for the '33' genotype, irrigation water use efficiency increased as irrigation water was reduced.

Yuan *et al.* (2004) stated that the water use efficiency is higher with reduced water use, which is similar to the conclusion of our current study. This study determined the "IWUE" values for Ep75, Ep1, and Ep1.25 crop-pan coefficients to be 1.69, 1.63, and 1.36 g mm⁻¹, respectively. In response to water limitation, Escalona *et al.* (1999) found that genotypes with high IWUE values exhibit significantly increased photosynthetic capacity and drought resistance (Bota *et al.*, 2001). The parameter mentioned above increased by 41% in the selected hybrid '112's deficit irrigation, revealing that this bred line is more drought resistant and, therefore, could perform high-level photosynthesis even in the experimented conditions. On the other hand, the '33' bred line is particularly vulnerable to drought, with a decrease of 7.8%, which is not predicted under deficit irrigation conditions.

Table 1. IWUE of strawberry genotypes under different irrigation regimes (g mm⁻¹plant⁻¹)

Genotypes	Irrigation water use efficiency		Genotype Average
	IR 100	IR 50	
'33'	1.42	1.31	1.36 ABC1
'36'	0.81	1.09	0.95 D
'59'	1.47	1.54	1.50 AB
'61'	1.09	1.40	1.25 BC
'112'	0.97	1.37	1.17 CD
'Rubygem'	1.19	1.49	1.34 ABC
'Festival'	1.17	1.26	1.21 CD
'Sabrina'	1.35	1.86	1.60 A
-Irr. Average	1.18 B	1.42 A	

LSDi***2= 0.13; LSDg***= 0.26; LSDi×g= N.S.

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant ***:p<0.001; **:p<0.01; *:p<0.05

(3): i: irrigation; g: genotype

Yields of strawberry genotypes under different irrigation regimes (g plant⁻¹)

Yield is one of the most crucial aspects of fruit production. In this regard, concerning breeding research, many relevant activities seek the primary purpose of increasing yield. It has been demonstrated in this study that the genotype has a considerable impact on production and irrigation. The average yield per plant of the trial was substantially greater at 859.8 g plant⁻¹ on IR100 than at 612.4 g plant⁻¹ on deficit irrigation (Table 2).

Table 2. Yields per plant for strawberry genotypes under different irrigation regimes (g plant⁻¹)

Irr.	Genotype	Harvest periods						Irrig.×Ge not.	Irrigation average
		January	February	March	April	May	June		
50	'33'	33.2 w-c	10.2 abc	62.7 q-c	322.1 f	92.9 k-w	46.1 t-c	567.2	612.4 B
	'36'	12.7 y-c	11.5 z-c	121.9 j-q	151.8 h-l	138.9 j-o	36.2 v-c	472.9	
	'59'	33.6 w-c	8.3 abc	57.1 q-c	410.8 cd	103.6 j-v	52.2 r-c	665.5	
	'61'	5.2 c	4.9 c	161.2 hjk	298.9 f	105.0 j-v	30.9 w-c	606.2	
	'112'	13.3 y-c	20.0 x-c	122.5 j-q	271.5 fg	145.4 j-n	19.9 x-c	592.7	
	'Sabrina'	3.1 c	4.2 c	167.9 hj	508.4 b	76.9 n-a	44.1 u-c	804.7	
	'Festival'	19.5 x-c	30.1 w-c	80.0 n-z	288.5 f	76.9 n-a	50.1 s-c	545.0	
	'Rubygem'	23.2 w-c	19.8 x-c	150.3 h-m	320.6 f	85.0 l-x	46.1 t-c	645.1	
I × HP		17.9 FG	13.6 G	115.5 DE	321.6 B	134.6 D	40.7 F		
100	'33'	31.2 w-c	7.3 abc	57.1 q-c	538.6 ab	121.3 j-r	273.9 fg	1029.4	859.8 A
	'36'	12.3 y-c	8.8 abc	81.3 m-y	217.6 gh	160.0 hjk	111.9 j-u	592.0	
	'59'	55.9 q-c	6.0 bc	66.6 p-c	473.9 bc	136.2 j-p	328.7 ef	1067.4	
	'61'	10.9 z-c	4.3 c	115.6 j-t	397.9 de	125.5 j-q	140.7 j-o	795.0	
	'112'	19.7 x-c	14.5 y-c	67.6 p-c	214.6 gh	269.1 fg	116.8 j-s	702.2	
	'Sabrina'	11.0 z-c	2.5 c	110.3 j-u	604.8 a	85.4 l-x	165.7 hj	979.7	
	'Festival'	44.8 u-c	24.8 w-c	109.0 j-u	429.9 cd	75.6 o-b	163.7 hj	847.8	
	'Rubygem'	23.9 w-c	16.9 x-c	146.4 j-n	429.3 cd	103.5 j-v	144.9 j-o	864.9	
I × HP		26.2 FG	10.6 G	94.2 E	413.3 A	103.1 E	180.8 C		
Harvest period averages		22.1 C	12.1 C	104.8 B	367.5 A	118.8 B	110.8 B		

LSDhp**= 17.4; LSDj***= 67.4; LSDg***= 20.1; LSDi×hp***= 24.6; LSDi×hp= N.S.; LSDg×hp***= 49.3; LSDi×g×hp**= 69.7

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant ***:p<0.001; **:p<0.01; *:p<0.05

(3): i: irrigation; g: genotype; hp: harvest period

When the genotypes were analysed separately, regardless of irrigation, the 'Sabrina' cultivar's overall yield was the highest, with 892.2 g plant⁻¹. The selected genotypes '59' and '33' in the same statistical group followed this cultivar with 866.5 and 798.3 g plant⁻¹. These bred lines produced higher yields than the 'Rubygem' and 'Festival' cultivars, which are popular in the Mediterranean region of Türkiye. The lowest yield was determined in the strawberry genotype coded '36' with a 532.5 g plant⁻¹ value. In this context, the genotype × irrigation interaction was statistically insignificant, and the yield declined as irrigation water application was reduced in all genotypes. The yield values per plant in this double interaction have been determined to range from 472.9 g plant⁻¹ ('36' × IR50) to 1067.4 g plant⁻¹ ('59' × IR100). The yield values differed significantly between months, where the highest yield (367.5 g plant⁻¹) was obtained in April. The yields of May, June and March are in the same statistical group, followed by April 118.8, 110.8 and 104.8 g plant⁻¹, respectively. Although the interaction between the irrigation regime and period is crucial in the study, it indicates how deficit irrigation has a negative effect over time by the temperature rises. While the difference between the effects of the irrigation regimes was insignificant until April, the yield declined dramatically in the following period and continued so as the temperature rose. Although this was most evident after April, the reduction in plant development and the bloom and fruit numbers of the previous periods indicated that the cumulative effect became more apparent in this period. The level of triple interaction had a statistically significant effect where yields ranged from 2.5 g plant⁻¹ ('Sabrina' × IR100 × February) to 604.8 g plant⁻¹ ('Sabrina' × IR100 × April).

Due to limited irrigation, yields were reduced, ranging from 15.8% ('112') to 44.9% ('33'), depending on the genotype. Similarly, earlier research has revealed that lower irrigation water reduced strawberry yield (Yuan *et al.*, 2004; Taparuskien and Miseckaite, 2014; Kapur *et al.*, 2018a). However, Bota *et al.* (2001) reported that the variety, which is more resistant to arid conditions, generally yields less under optimal conditions. In the current research, conformably, under deficit irrigation conditions, the '33' and '59' coded bred lines with high yields were more affected than the others. Furthermore, the decrease rates of the yields in the '36' and '112' bred lines were 20% and 15.8% lower than the others, respectively. When commercial cultivars were compared for yields, the Sabrina cultivar's reduction was the highest by only 17.9%. Different reactions among the genotypes can be encountered by root structure, stomata number, stoma size variation, and morphological characteristics, like the genotype that changes in the internal drought mechanism may induce. Similar research experiments revealed that limiting irrigation reduced yields (Yuan *et al.*, 2004; Kapur *et al.*, 2018a; Sarıdaş *et al.*, 2021a). In this respect, there may be a connection between the decline in leaf N, P, K, Mg, Cu, and Mn levels and the reduction in nutrient uptake from the soil, as mentioned by Celiktopuz *et al.* (2021). Consequently, the outcomes of our study, together with the earlier, revealed that applying the right amount of irrigation is essential for obtaining good and high-quality yields. Moreover, these contemporary studies have shown that irrigation levels should be scheduled based on genotypes, i.e., deficit irrigation should be avoided for sensitive genotypes. In contrast, other irrigation water application strategies may be developed for tolerant ones.

Fruit weights of strawberry genotypes under different irrigation regimes (g/fruit)

The average fruit weights of strawberry genotypes under different irrigation regimes are presented in Table 3. The variables' impact was statistically insignificant except for irrigation regime and harvest time on fruit weight. As expected, the average fruit weight of IR 100 was 13.8 g and significantly higher than that of IR 50 (12.1 g) when irrigation was increased. Fruits harvested in March, with an average weight of 18.2 g, had the highest fruit weight compared to the fruit weights of the other months. The first harvest followed March in January and February with 15.0 and 13.9 g fruit weights. April's 12.6 g fruit weight declined dramatically due to increased temperature and decreasing plant charge, with the lowest fruit weight of 7.1 g recorded in June. The average fruit weight varied up to 5 times during the season, ranging from 3.93 to 21.4 g, despite the insignificant triple interaction value.

Table 3. Fruit weights of strawberry genotypes under different irrigation regimes during the cultivation season (g/fruit)

Irrigation	Genotype	Harvest period						Irrig.× Genot.	Irrigation average
		January	February	March	April	May	June		
50	'33'	15.4	8.6	15.0	8.5	7.1	4.5	9.9	12.1 B
	'36'	11.9	14.7	16.2	13.0	10.2	5.1	11.9	
	'59'	15.4	7.5	18.1	10.6	7.7	3.9	10.6	
	'61'	11.7	14.7	16.8	10.9	8.5	3.9	11.1	
	'112'	17.1	16.2	19.5	13.7	11.6	4.3	13.7	
	'Sabrina'	11.9	11.3	20.6	13.2	10.3	4.4	11.9	
	'Festival'	20.5	15.4	16.9	12.3	8.5	9.7	13.9	
'Rubygem'	14.7	19.4	19.9	13.7	9.9	5.5			
I × HP		14.8	13.5	17.9	11.9	9.2	5.2		
100	'33'	19.4	9.2	16.2	10.9	10.3	8.9	12.5	13.8 A
	'36'	10.7	13.8	17.6	14.0	15.6	10.5	13.7	
	'59'	16.1	7.5	17.2	10.6	10.8	8.6	11.8	
	'61'	14.5	14.6	19.1	12.9	10.7	6.8	13.1	
	'112'	11.8	17.9	16.8	15.5	17.5	10.0	14.9	
	'Sabrina'	16.3	20.8	21.4	14.3	11.7	9.8	15.7	
	'Festival'	19.0	14.3	18.9	12.6	10.0	8.4	13.9	
'Rubygem'	13.9	17.2	20.9	14.5	12.7	8.6	14.6		
I × HP		15.2	14.4	18.5	13.2	12.4	8.9		
Harvest period ave.		15.0 B	13.9 BC	18.2 A	12.6 C	10.8 D	7.1 E		
LSD _{hp} ***= 1.66; LSD _i ***= 0.96; LSD _g ***= 1.91; LSD _{ixhp} = N.S.; LSD _{ixg} = N.S.; LSD _{gxhp} *= 4.69; LSD _{ixgxhp} = N.S.									

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant***: p<0.001; **: p<0.01; *: p<0.05

(3): i: irrigation; g: genotype; hp: harvest period

Another study with similar findings indicated that the size of the fruit significantly decreased as the season went on, regardless of the irrigation schedule or time of the year. Even though fruit size changes with irrigation levels, significantly smaller fruits were detected under IR 50 regimes. Earlier studies have reported weight reduction in strawberry fruits under deficit irrigation conditions (Saridaş *et al.*, 2017; Celiktopuz *et al.*, 2018; Kapur *et al.*, 2018a; Saridaş *et al.*, 2021a) where genotypes were further stated to have considerable effects on fruit weight by Saridaş *et al.* (2021b). While the largest fruits of 13.8 g were determined in the '112' coded 'Rubygem', the 'Sabrina' genotype of the same statistical group followed '112' by 13.1 g. The '33' and '59' bred lines with the highest fruit yield had the lowest fruit weights. This situation could be related to the competition among the fruits depending on the high yield level.

Leaf area values of strawberry genotypes (cm²plant⁻¹)

Findings related to leaf area during the season, which directly reflect the development of plant vegetative parts, are reported in Table 4. Statistical analyses revealed that all the parameters examined and their interactions have a significant impact on the leaf area. As expected, with the season's progress, the leaf area increased significantly and reached the highest level (3165.1 cm²/ plant⁻¹) in May, whereas it decreased significantly (2017 cm²) in the IR50 regime. The genotypes were found to be easily recognizable from commercial cultivars with high leaf areas like the '33' bred line with a significantly higher leaf area than the others (3155.8 cm²), except for the chosen hybrid coded '36' and the 'Rubygem' with the lowest leaf area per plant (1770 cm²). Although the genotypes' responses to deficit irrigation differed, the reduction in leaf area in genotypes ranged from 29 to 41%, whereas 'Rubygem's reduction was just 5%. In this respect, the 'Rubygem',

with the lowest leaf area, appears to be the least affected by reduced irrigation due to its smaller leaf area compared to the others. This cultivar was found to be followed by the '36' bred line, which had a lower leaf area and a declining value of 29%. These findings revealed that genotypes with lower leaf areas might be more tolerant to water stress. When the impacts of triple interaction values on leaf area are investigated throughout the season, it has been revealed that this value varies up to 4.5 times, ranging from 1081 to 4938 cm² plant⁻¹.

Table 4. Leaf areas of strawberry genotypes under different irrigation regimes during the cultivation season (cm² plant⁻¹)

Irrigation	Genotype	Harvest period			Irrig.×Genot.	Irrigation average
		March	April	May		
IR50	'33'	2827 f-k	1970 n-s	2707 g-k	2501 EF	2017 B
	'36'	1081 v	1714 q-u	2517 j-n	1771 H	
	'59'	1522 s-v	2556 j-m	2780 g-k	2286 FG	
	'61'	1386 tuv	1890 o-t	3209 d-g	2162 GH	
	'112'	1559 r-v	2572 j-m	2530 j-m	2220 FG	
	'Sabrina'	1248 uv	1968 n-s	2355 k-p	1857 H	
	'Festival'	1642 q-u	1392 tuv	1833 p-t	1622 H	
'Rubygem'	1196 uv	1890 o-t	2077 m-r	1721 H		
I × HP		1558 F	1994 E	2501 C		
IR100	'33'	3158 e-h	336 c-f	4938 a	3810A	3044 A
	'36'	1205 uv	2324 k-p	3939 b	2489 EF	
	'59'	2504 j-n	3943 b	3775 bc	3407 B	
	'61'	2965 f-j	2773 g-k	3937 b	3224 BC	
	'112'	2630 h-l	3967 b	4723 a	3773 A	
	'Sabrina'	2409 k-o	3087 fgh	3661 b-e	3052 CD	
	'Festival'	2076 m-r	2507 j-n	3758 bcd	2780 DE	
'Rubygem'	1406 tuv	2148 l-q	1906 o-t	1819 H		
I × HP		2294 D	3010 B	3829 A		
Harvest period ave.		1926 C	2502 B	3165 A		
LSDhp***= 137.9; LSDi***= 112.6; LSDg***= 225.2; LSDi×hp***= 195.0; LSDi×g***= 318.4; LSDg×hp***= 390.0; LSDi×g×hp***= 551.5						

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant ***:p<0.001; **:p<0.01; *:p<0.05

(3): i: irrigation; g: genotype; hp: harvest

Grant *et al.* (2010) investigated the morphological changes of plants in 10 strawberry cultivars under regular and reduced irrigation conditions. They found remarkably similar results, although under water stress, leaf area, plant number, and leaf and root dry weight all reduced dramatically, and cultivars responded to deficit irrigation at varied levels. Thus, researchers concluded that cultivars with lower leaf areas might be advantageous in cultivar selection for drought tolerance. Klamkowski *et al.* (2015) revealed that under stress conditions, the total leaf area of the 'Honeoye' cultivar reduced significantly compared to the control. Previous studies revealed that considerable leaf area reductions were inevitable under limited irrigation conditions (Rucker *et al.*, 1995; Klamkowski and Treder, 2008; Kapur *et al.*, 2018b; Sarıdaş *et al.*, 2021a) and consequently, plant growth (Hsiao, 1973). In this respect, leaf area may be the most important variable in breeding research for drought-resistant cultivars, based on this and earlier findings. Thus, the bred line code '36', may be noteworthy in terms of flavour, colour, yield, and responses to water stress in this study and our previous breeding trials.

Photosynthesis and strawberry genotypes ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)

Photosynthesis is one of the first and most crucial processes in plant development. The effects of the investigated factors on the variations of the photosynthesis values of strawberry plants are presented in Table 5. The influence of all parameters on photosynthesis and leaves was found to be statistically significant. When the harvest periods were compared, we found that the maximum level of photosynthesis occurred in April, with a value of $10.9 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, which was much greater than the other months, and the lowest reading was $6.7 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ measured in March. As expected, the plant's photosynthetic capacity reduced dramatically under limited irrigation conditions to $6.9 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ from $11.2 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$. When genotypes were compared, the '33' bred line had a much better photosynthetic capacity ($9.6 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) than the others. This bred line was followed by the '59' with a value of $9.4 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, whereas the photosynthesis level of the 'Rubygem' cultivar was $8.6 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and the lowest. We determined that the irrigation level \times genotype interaction values ranged from $6.7 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ to $11.6 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, noting that the photosynthesis levels decreased in the investigated genotypes due to deficit irrigation. Under the triple factor effect, photosynthetic levels fluctuated from $5.45 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ to $13.95 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ throughout the season.

Table 5. Photosynthesis values of strawberry genotypes under different irrigation regimes during the cultivation season ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)

Irrigation	Genotype	Period			Irrig. \times Genot.	Irrigation average
		March	April	May		
IR50	'33'	6.0 rst	8.9 h	6.8 no	7.3 F	6.9 B
	'36'	5.9 st	8.1 kl	6.2 qrs	6.7 H	
	'59'	5.8 tu	8.9 h	6.8 no	7.1 FG	
	'61'	5.7 tu	8.8 h	6.6 op	7.0 GH	
	'112'	5.9 rst	8.4 jk	6.3 pqr	6.9 H	
	'Sabrina'	5.5 u	8.7 hj	6.6 op	6.9 GH	
	'Festival'	6.2 qrs	8.3 k	6.3 pqr	6.9 H	
	'Rubygem'	6.0 rst	8.3 k	6.3 pqr	6.9 H	
I \times HP		5.9 F	8.5 C	6.5 E		
IR100	'33'	8.5 jk	13.9 a	13.4 bc	11.9 A	11.2 A
	'36'	8.2 k	12.8 ef	12.2 g	11.1 CD	
	'59'	7.8 l	13.8 a	13.3 cd	11.6 B	
	'61'	6.9 no	13.7 ab	13.1 cde	11.2 C	
	'112'	7.8 l	13.1 cde	12.5 fg	11.1 C	
	'Sabrina'	7.0 mn	13.4 bc	12.8 ef	11.1 CD	
	'Festival'	7.3 m	12.9 de	12.4 g	10.9 D	
	'Rubygem'	6.5 opq	12.8 ef	12.2 g	10.5 E	
I \times HP		7.5 D	13.3 A	12.7 B		
Per. Ave.		6.7 C	10.9 A	9.6 B		
LSDhp***= 0.09; LSDi***= 0.079; LSDg***= 0.16; LSDi \times hp***= 0.14; LSDi \times g***= 0.23; LSDg \times hp***= 0.28; LSDi \times g \times hp***= 0.39						

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant; ***:p<0.001; **:p<0.01; *:p<0.05

(3): i: irrigation; g: genotype; hp: harvest period

Photosynthesis and, thus, the related parameters such as yield and vegetation have been shown to have diminished under deficit irrigation. Like this study, Anjum *et al.* (2011) found that leaf development and growth were negatively affected under limited irrigation conditions. Perin *et al.* (2019) reported that under 70% and 50% irrigation, carbon dioxide assimilation was reduced by 29.16% and 58.69%, respectively, compared to the control. This experiment revealed that, depending on the genotype, the decrease rate varied

from 34.4% to 39.4% with a 50% limited irrigation application. Similar findings were observed by Klamkowski *et al.* (2015), who reported that yields were reduced by 26 to 59% depending on the variety under limited irrigation conditions when compared to the control. The variations between studies appear primarily due to the genotypes used. However, other factors such as fertilizers, mulch colour, and pesticide use may also impact this rate. Furthermore, these findings reveal that genotypes differ in their drought tolerance.

Stomatal Conductivity of Strawberry genotypes ($\mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$)

The decrease in stomatal conductivity is one of the major plant stress markers. The data obtained from the trial during the season are presented in Table 6. All of the evaluated factors and their interactions had statistically significant effects on leaf stomatal conductivity. The maximum stomatal conductivity of the different statistical groups was observed in April with a value of $497.2 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$, followed by values of $455.6 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$ and $227.0 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$ in May and March, respectively. As expected, stomatal conductivity decreased significantly in deficit irrigation application, measuring $287.0 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$. When the genotypes were compared, the bred line '33' showed a substantially higher stomatal conductivity ($437.9 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$) than the others. This bred line was followed by '61' and the 'Festival' cultivar from different statistical groups, with values of $407.0 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$ and $401.1 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$.

Table 6. Stomatal conductivity ($\mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$) of strawberry genotypes under different irrigation regimes during the cultivation season

Irrigation	Genotype	Period			Irrig.×Genot.	Irrigation average
		March	April	May		
50	'33'	231.5 x	447.0 l	340.5 p	339.7 H	287.0 B
	'36'	210.5 yz	38.6 e	290.0 t	179.7 M	
	'59'	206.5 za	335.5 p	252.5 w	264.8 L	
	'61'	190.5 b	424.0 m	315.5 q	310.0 I	
	'112'	199.5 a	398.5 o	307.0 qrs	301.7 J	
	'Sabrina'	160.0 d	410.0 n	311.0 qr	293.7 K	
	'Festival'	234.5 x	401.0 o	305.0 rs	313.0 I	
	'Rubygem'	181.0 c	396.0 o	302.0 s	293.0 K	
I × HP		201.8 F	356.3 C	302.9 D		
100	'33'	252.0 w	693.5 a	663.0 c	536.2 A	499.6 A
	'36'	260.0 vw	600.0 h	574.0 k	478.0 F	
	'59'	268.5 uv	673.5 b	644.0 d	528.7 B	
	'61'	217.0 y	661.0 c	634.5 e	504.2 C	
	'112'	264.5 uv	621.0 f	592.0 i	492.5 E	
	'Sabrina'	252.5 w	636.0 de	608.0 gh	498.8 D	
	'Festival'	272.0 u	611.5 g	582.5 i	488.7 E	
	'Rubygem'	232.0 x	608.0 gh	568.5 k	469.5 G	
I × HP		252.3 E	638.1 A	608.3 B		
Per. Ave.		227.0 C	497.2 A	455.6 B		

LSD_{hp}***= 2.15; LSD_i***= 1.76; LSD_g***= 3.51; LSD_i×hp***= 3.04; LSD_i×g***= 4.97; LSD_g×hp***= 6.09; LSD_i×g×hp***= 8.61

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant; ***:p<0.001; **:p<0.01; *:p<0.05

i : irrigation ; g ; genotype ; hp ; harvest period

In comparison, the lowest stomatal conductivity was detected in the '36' bred line with a value of $328.9 \mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$. The maximum stomatal conductivity value was found in April when the genotype × period interaction was evaluated. However, for the genotype coded '36', the value was substantially greater in May than in April. The genotypes with the lowest stomatal conductivity value were measured in March. In genotype

× irrigation interaction, significant reductions in stomatal conductivity were found in genotypes against deficit irrigation. The magnitude of these reductions varied depending on the genotype, ranging from 35.8% ('Festival') to 62.4% ('36'). This decline (36.6 percent) was less in the '33' bred line against deficit irrigation when selected superior genotypes were assessed within themselves. The reduction in commercial varieties ranged from 35.8% in 'Festival' to 41.3% in 'Sabrina'. The triple interaction revealed that stomatal conductivity values varied up to 18 times, ranging from 38.6 to 683.5 $\mu\text{mol H}_2\text{O m}^{-2}\text{s}^{-1}$. This could be due to the genotypes' different responses to environmental factors and agricultural practices like irrigation. In addition to selecting the appropriate genotype, controlling environmental factors like temperature and humidity and agricultural techniques is essential for healthy plant development to offer optimal stomatal conductivity in such plants.

In another study, reduced irrigation water was determined to cause a dramatic reduction of stomatal conductivity in the experimental plant material (Kapur *et al.*, 2018b). We found in the current study that this decline varies by genotype and might be related to genotype-specific stress responses. Although the high response is essential for plants to survive under water stress, it may harm plant development and CO_2 uptake.

Leaf water potential of strawberry genotypes (bar)

The leaf water potential of the plants studied was significantly affected by all the parameters ($p \leq 0.01$) measured during the growing season. The LWP values obtained by applying different factors throughout the season are shown in Table 7.

Table 7. Leaf water potential of strawberry genotypes under different irrigation regimes during the cultivation season (bar)

Irrigation	Genotype	Period			Irrig.×Genot.	Irrigation average
		March	April	May		
IR50	'33'	- 11.2 r	- 16.0 h	- 19.3 d	- 15.5 D	- 15.1 A
	'36'	- 11.8 q	- 14.1 l	- 13.1 m	- 12.9 H	
	'59'	- 11.9 pq	- 14.9 j	- 15.0 j	- 13.9 F	
	'61'	- 12.5 n	- 18.5 e	- 14.3 kl	- 15.1 E	
	'112'	- 12.0 opq	- 17.0 g	- 22.1 a	- 17.0 A	
	'Sabrina'	- 11.0 r	- 18.5 e	- 19.7 c	- 16.4 B	
	'Festival'	- 11.7 q	- 14.9 j	- 21.1 b	- 15.9 C	
	'Rubygem'	- 10.8 r	- 18.0 f	- 12.0 opq	- 13.6 G	
I × HP		- 11.6 D	- 16.5 B	- 17.1 A		
IR100	'33'	- 7.5 v	- 14.3 kl	- 12.4 no	- 11.4 K	- 11.7 B
	'36'	- 9.0 t	- 12.3 nop	- 10.4 s	- 10.6 M	
	'59'	- 9.0 t	- 14.3 kl	- 11.8 q	- 11.7 J	
	'61'	- 9.0 t	- 16.0 h	- 10.2 s	- 11.7 J	
	'112'	- 10.1 s	- 16.1 h	- 14.5 jk	- 13.6 G	
	'Sabrina'	- 9.3 t	- 14.5 jk	- 12.3 nop	- 12.0 J	
	'Festival'	- 9.2 t	- 12.0 opq	- 14.4 kl	- 11.7 J	
	'Rubygem'	- 9.0 t	- 16.3 h	- 8.0 u	- 11.1 L	
I × HP		- 9.0 E	- 14.5 C	- 11.7 D		
Per. Ave.		- 10.3 C	- 15.5 A	- 14.4 B		

LSDhp***= 0.11; LSDi***= 0.085; LSDg***= 0.17; LSDi×hp***= 0.15; LSDi×g***= 0.24; LSDg×hp***= 0.29; LSDi×g×hp***= 0.42

(1): Differences between the means are shown with separate letters

(2): N.S.: Non-Significant ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$

(3): i: irrigation; g: genotype; hp: harvest period

The lowest LWP value in plants was measured in April (-15.5 bar) during the harvest season, followed by the May (-14.4 bar) and March (-10.3 bar) measurements of the different statistical groups. The amount of

water in the plant may decrease due to increased production in the maximum harvest period (April), decreasing due to rising temperatures in May (compared to March). The amount of water in the plant declined after reduced irrigation to -15.1 bar in IR50 and -11.7 bar in IR100. When genotypes are compared, the highest water potential in leaves was measured at -11.8 bar in the '36', while the lowest value was -15.3 bar in the '112' bred line. This variation is indirectly assumed to be related to the plant's green sections. The '36' bred line and the 'Rubygem' cultivar with the lowest leaf area had the highest LWP but were much lower within the selected genotype with the maximum leaf area coded '112'. In this respect, we may conclude that as the leaf area rises, the LWP level falls. When the genotype \times harvest time interaction was investigated, the water potential in the leaves of '33', '112', and 'Festival' was lowest in May but lowest in April in the other genotypes. The maximum LWP value was recorded in March in all genotypes.

Moreover, a decrease from 15.8% to 26.7% in genotypes against deficit irrigation was determined in the LWP. Despite the same amount of irrigation water reduction, the plants developed various stress mechanisms and responses at different levels. This could be due to variations in yield production, green part density, or genotype root structure. The LWP value fluctuated up to three times over the season, ranging from -7.5 bar to -22.1 bar, depending on the application and development stage.

Due to deficit irrigation, the amount of water in the leaf decreased significantly; the highest LWP was found in the '36' bred line with the lowest stomatal conductivity. Although the relationship between these parameters is a well-known physiological mechanism, we now know that various genotypes have evolved a crucial drought-resistance mechanism by reducing stomatal conductance and preserving the water potential of the plant during decreased irrigation. In this respect, we found that the LWP was similarly rapidly enhanced as the irrigation water increased (Kapur *et al.*, 2018b).

The relations between some parameters of major importance

The relationship between the parameters examined in the study and the combination of factors is presented in Figure 2 by principal component analysis (PCA). The total variation of 51% and 24% was explained by PC1 and PC2. The primary parameter (PC1) had positive loading from stomatal conductivity, photosynthetic activity and leaf area, whereas the second (PC2) was the positively associated leaf water potential and average fruit weight. In this respect, this study showed that the strawberry yield was directly related to stomatal conductivity ($r^2=0.53$), photosynthetic activity ($r^2=0.52$), and LWP ($r^2=-0.36$), consequently pointing out to the increase of these parameters when the strawberry yield increased. Moreover, this was followed by a significant increase in leaf area, photosynthetic activity ($r^2=0.68$), and stomatal conductivity ($r^2=0.67$) in the plant.

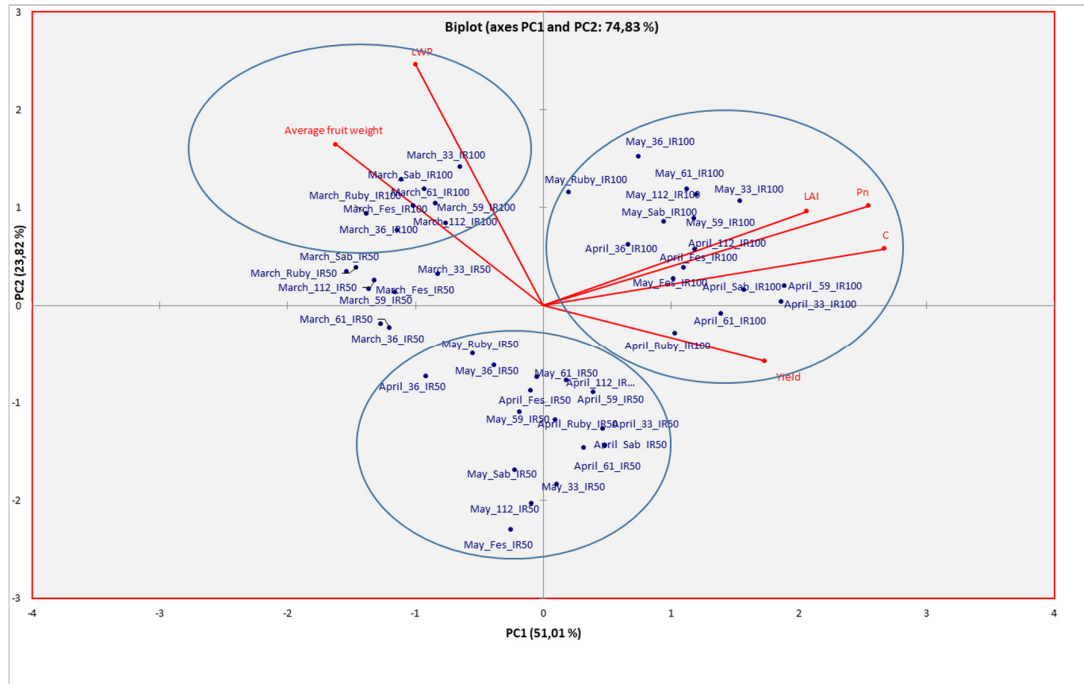


Figure 2. Interrelation between the examined parameters and combination of harvest period × genotype × irrigation by the principal component analysis (PCA)

This situation can be explained indirectly concerning the vital role of sufficient water and nutrients in increasing plant leaves and avoiding plant stress. This documents that high photosynthetic activities and stomatal conductivities are expected in plants that are not stressed. Thus, in this context, PCA results confirmed that the highest photosynthetic activity, stomatal conductivity and leaf area values were achieved under full irrigation conditions in May and April. Furthermore, PCA results revealed that the highest yield was also achieved in the genotype combination in April at full irrigation conditions. The average fruit weight and leaf water potential for both irrigation regimes were highest in March, even though the effects of the stress conditions were not yet completely apparent.

Conclusions

The average global temperature is predicted to rise in the next decades due to climate change which is predicted to increase the crop water requirement, leading to a worldwide drought (Feng and Fu, 2013). Many nations, including Turkey, are investigating the effects of this global warming-related challenge on agricultural production. Photosynthesis activity, stomatal conductivity, and LWP values, all of which are positively associated with yield, were found to be relevant in determining yield per plant in our study. This study reflects that when plants are stressed, their stomata close to maintain the leaf water balance, resulting in decreased photosynthetic activity due to decreased CO₂ intake. This was demonstrated in the context of this study, where stomatal conductivity was determined to decrease via the closure of the stomata due to decreasing irrigation.

Consequently, the photosynthetic activity was also reduced as the CO₂ entering the plant dropped through the closing stomata. Similarly, it was observed that the soil water intake decreased due to a possible decrease in the osmotic potential of the roots due to stomata closure, hence decreasing the plant's water potential. Thus, the plant intake of water and nutrients from the soil was decreased, as well as the CO₂ uptake due to this physiological process, caused by the leaf area reduction as a first sign of stress indicated by the

diminishing number of stems and their thickness. Consequently, the average fruit weight reduced dramatically due to the decrease in the relevant parameters, causing a significant decrease in yield per plant. As the strawberry cultivation season progresses, the plant is highly affected by stress conditions, and the severity of the processes mentioned above increases. The high yielding '33' bred line was determined to be the only genotype with a reduced water use efficiency. In this context, it was documented that that the fruit size of the selected low-yield genotype coded '36', belongs to the same class as commercial varieties, but the yield remains very low due to the low number of fruits.

In contrast, the bred line '33', where the eco-physiological parameters were directly related to the yield, had higher levels of photosynthetic activity and stomatal conductivity than the others. Moreover, the bred line '36', with lower yields, had lower levels of photosynthesis activity and LWP. These and related criteria are useful as markers in species like strawberries, which are renowned for being challenging in obtaining the total yield value. Thus, it is possible to select high-yielding genotypes with the measurements to be made in April and May during the highly crop-yielding period. Consequently, we demonstrated in this study that, in addition to selecting the right genotype for strawberry growth, cultural activities like irrigation significantly impact yield and fruit quality.

Authors' Contributions

Conceptualization: MAS and BK; Data curation: MAS, BK, EÇ and SPK; Formal analysis: MAS and BK; Funding acquisition: MAS; Investigation: MAS and BK; Methodology: MAS, BK, SPK; Project administration: SPK; Resources: BK; Supervision: SPK; Writing - original draft: MAS; Writing - review and editing: BK. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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