THE ROLE OF MULCH COLOR AND IRRIGATION LEVEL IN REDUCING WATER STRESS IN STRAWBERRY

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Abstract. Photosynthesis decline, resulting from changing evapotranspiration levels and varying growing conditions, can lead to crop failure. To prevent damage, it is essential to assess carotenoid and chlorophyll content, and crop responses to limited irrigation. In this experiment, we studied strawberry responses to photosynthetic pigments, physiological parameters, and macronutrient concentrations under different irrigation levels (IR100 and IR50), mulch colors (black, silver, transparent), and harvest dates in Turkey. The results showed significant effects on total chlorophyll, chlorophyll a, chlorophyll a/b, and carotenoid levels due to irrigation and dap applications. Fruit N, P, and K concentrations were significantly influenced by irrigation and mulch colors but unaffected by different periods. Leaf water potential (ΨL) and stomatal conductance (gs) were significantly impacted by all treatments. Silver mulch retained more water (31%) and had higher gs (28%) than other treatments. Silver and black mulch resulted in the highest macro nutrient concentrations in the fruit. IR50 reduced chlorophyll and carotenoid levels, ΨL, gs, and N, P, and K concentrations. Our findings highlight the benefits of using appropriate mulch colors and irrigation amounts, with silver mulch × IR100 combination mitigating the impact of limited irrigation under Mediterranean climate conditions.
Keywords: *chlorophyll, carotenoid, drought, stomatal conductance, Mediterrenian climate*

Introduction

Strawberries hold a significant position in the European market, valued for their delightful flavor, aromatic qualities, and high vitamin and mineral content (Kumar and Dey, 2011). In Turkey, the southern province has emerged as a major strawberry-producing region, benefitting from its favorable climate and early harvest dates, making strawberry cultivation both profitable and popular among growers in this area. However, to ensure optimal productivity and fruit quality, proper irrigation water management is of paramount importance. Proper irrigation management is crucial for strawberry cultivation due to the high-water content of the fruit, large leaf area, and shallow root structure (Grant et al., 2010). Numerous studies have shown that irrigation timing and amounts significantly affect strawberry growth and fruit yield (Yuan et al., 2004). Physiological characteristics like ΨL and gs as well as fruit weight and size, have been found to be positively correlated with irrigation water usage (Kapur et al., 2018).

Mulching, a widely adopted practice in strawberry cultivation, offers multiple benefits, including reducing fruit decay by preventing direct contact with the soil and enhancing water use efficiency (Sarıdaş et al., 2021). Mulch treatments are one of the most important

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agricultural practices to consider in conjunction with a well-designed irrigation system. Mulching reduces water loss from evaporation from the soil which reduced water stress on strawberry (Kırnak et al., 2001; Kumar and Dey, 2011). Besides, mulching maintains a desirable soil temperature (Kumar and Dey, 2011), protects the soil from frost (Barrales-Dominguez and Alejo-Santiago, 2002), decreases water and wind erosion and soil movement (Liang et al., 2002), increases the amount of useful nutrients and organic matter (Kumar and Dey, 2011), improves root system development in plants (Kumar and Dey, 2011), and plays an important role in increasing the fruit yield and quality (Estes et al., 1985). Kumar and Dey (2011) found that mulching enhanced plant root growth by 63%, nutrient uptake by 189%, effective water utilization by 84.40%, and yield by 343% Using different colored mulches can produce a variety of interesting results. The yield and fruit size of tomatoes produced on red mulch were superior than those grown on black mulch (Kasperbauer and Hunt, 1998). Similarly, red mulch was found to increase strawberry productivity and fruit size more than black mulch (Kasperbauer, 2000). According to Kasperbauer's (2000) research cotton grown on red and green mulches had longer fiber length than cotton grown on white and aluminum mulches. Another study indicated that carrots grown on white and yellow mulch had the highest contents of β-carotene and ascorbic acid (vitamin c) (Loughrin and Kasberbauer, 2002). The application of black polyethylene mulch to strawberries was found to maintain soil moisture at a level of between 2.80-12.80% and increase soil temperature an average of between 0.4 to 2.5°C when compared to no mulch.

Water, photosentetic activity, temperature mulch type, irrigation, and harvest year are all crucial aspects of growing high-quality strawberries (Celiktopuz et al., 2021; Sarıdaş et al., 2021). Agricultural production is experiencing challenges due to climate change and fluctuate weather conditions. Varying evapotranspiraton (Et) rates brought on by irregular weather patterns are associated with a reduction in photosynthesis, and in crop failure. It is important to evaluate the carotenoid and chlorophyll contents, as well as their responses to water stress, In addition to inhibiting chlorophyll breakdown in the presence of light and oxygen and absorbing light energy at specific wavelengths and transferring it to chlorophyll, carotenoids are known to be the pigment that protects plants against photooxidative processes (Kacar, 1972). This research focuses on the effects of different irrigation schedules and mulching colours on photosyntehesis-related parameters, ΨL and gs as well as the concentrations of N, P, and K in the fruit of the strawberry. Mulch color types were used in the mulching application, and the combination of water stress and its effects on plant physiology were thoroughly investigated.

Materials and methods

Study site and agronomic practices

The research was conducted in the experimental area of the Department of Horticulture Science at Cukurova University/Turkey during the 2016-2017 strawberry growing season. The testing site is in Adana, at 36°59' N and 35°18' E, with an average elevation of 40 m above sea level (*Fig. 1*).

The soil had an average pH of 7.56; salt content was 0.35 mmhos/cm; volume weight was 1.33-1.41 g/cm^3; field capacity was 24.9-26.3 g/g; and wilting point was 13.1-15.7 g/g. The soil in the trial region has been confirmed to be loamy along the profile, and the amount of usable water in the 80 cm profile depth was 124 mm. Furthermore, total lime was found to be 12.30%.

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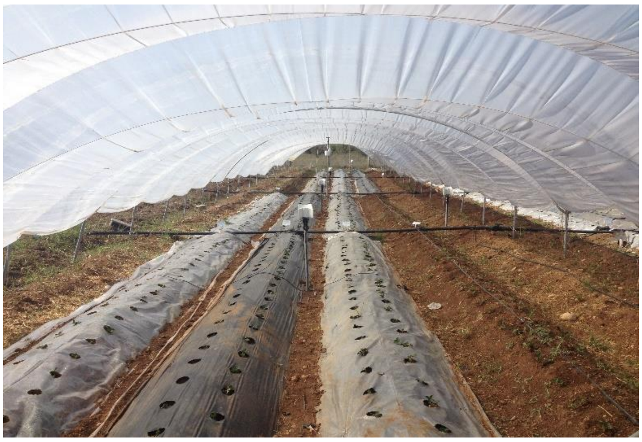

Figure 1. *Experimental area*

Long-year temperature and humidity data were compared to the current research period and found that the average air temperature and humidity were 0.05°C and 6.6% lower, respectively, but extremely similar to their long-year averages. As a result, the strawberry growing season of 2017-2018 matches the overall climatic conditions.

Frigo type plant material Fortuna (*Fragaria × ananassa* Duch. Cv.) was used in the trail. Although Fortuna has a short-day variation, it was chosen for its early ripening, good shape and size with high fruit firmness for the Mediterranean climate condition. After the soil was prepared (deep ploughing, leveling), raised beds were formed (70 cm width, 35 cm height, and 40 cm spacing between two banks) for strawberry cultivation. A 0.05 mm thick polyethylene mulch cover in various colors (transparent, silver, and black) was used to cover the beds. Various colors mulches were compared to one other and to control plots in this study (no mulch). Frigo type plants were arranged in double rows with a triangle-shape on the raised bed at 30 cm intervals. The plants were cultivated in Spanish-type high tunnels that were 6.5 m wide, 2.75 m high, and 40 m long, with UV, IR, AB, EVA, and LD additives, and were over 36 months old. All plots were subjected equal amount water until plants reached trifoliate stage, approximately two months from planting. Both irrigation and fertilization were conducted using the drip irrigation method. According to our prior studies, fertilizing and spraying the plants in issue were applied equally, in a controlled manner, in accordance with plant and soil requirements, and the experiment was carried out in a healthy manner.

The frigo type plant, which is a cultivar of the Fortuna variety, was planted on September 20, 2017, under various colored mulch and subjected to the different irrigation levels (0; accepted as the first day) until June 19, 2018.

Irrigation management

The drip irrigation system is comprised of the fertilizer tank, main pipe, water distribution pipes (Lateral), and drippers. Laterals are 16.00-mm-diameter flexible polyethylene pipes. The parcel's irrigation water was delivered by a 50 PVC main pipeline. One dripper with a flow rate of 3.5 lt/h was positioned at 30 cm intervals between two rows of plants on the beds for drip irrigation. Two different irrigation regimes were applied that consisted of the full irrigation application (IR100), in which the plant receives all of the water it requires, and half of the full irrigation applications (IR50). In our research, the use of pan evaporation was a well-established and standard

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practice in the field of agricultural water management, and it allowed us to estimate ET_0, which served as a basis for designing the initial irrigation treatments. The strawberry crop was irrigated once a week during the early phases of plant establishment (until dap 195) and then every two days until the plants had reached maturity, as advised by Yuan et al. (2004). The irrigation water was calculated using evaporation values derived from a class A pan. Water amounts were determined using the procedure below (*Eq. 1*) in accordance with earlier research (Yuan et al., 2004; Kapur et al., 2018; Sarıdaş et al., 2021).

$$Ir = Epan \times Kcp \times fc \quad \text{(Eq.1)}$$

where Ir = irrigation water amount (mm), Epan = cumulative free surface water evaporation at irrigation interval (mm), Kcp = plant pan coefficient (IR100, $Kcp_1 = 1.00$; IR50, $Kcp_2 = 0.50$), fc = wetting factor (%).

Photosynthetic pigments

To evaluate the concentrations of chlorophyll and carotenoids, fresh leaf samples (100–200 mg) (approximately 10 leaves) were homogenized in 10 ml of 80% (v/v) acetone on the 250th day after planting. The filtered samples were analyzed for total chlorophyll at 652 nm, chlorophyll a at 663 nm, chlorophyll b at 645 nm, and carotenoid analyses at 470 nm. To measure their amounts, Lichtenhaler and Wellburn's (1983) formulas were also utilized (A: Absorbance value as measured).

$$\text{Total chlorophyll} = A652 \times 27.8 \times 20 \text{ / mg sample weight} \quad \text{(Eq.2)}$$

$$\text{Chlorophyll a (KL a)} = (11.75 \times A663 - 2.35 \times A645) \times 20 \text{ / mg sample weight} \quad \text{(Eq.3)}$$

$$\text{Chlorophyll b (KL b)} = (18.61 \times A645 - 3.96 \times A663) \times 20 \text{ / mg sample weight} \quad \text{(Eq.4)}$$

$$\text{Carotenoid} = ((1000 \times A470 - 2.27 \times Kla - 81.4 \times Klb) / 227) \times 20 \text{ / mg sample weight} \quad \text{(Eq.5)}$$

Macro nutrient analysis in fruit (%)

To determine the effects of irrigation schedules and the application of mulch combined, some of the fruit's macronutrient concentrations (N, P, and K) were evaluated. Fruit samples were taken at the 250^{th} day after planting (dap) for each individual. Fruit samples were randomly selected from 10-15 plants and washed with dilute HCL (0.1%) and then twice with pure water. The fruits (divided into different parts) were stored at 70°C in the drying oven until they acquired a stable weight. The entire procedure was carried out as Celiktopuz et al. (2021) had stated.

Physiological evaluations

Stomatal conductivity (μmol m^{-2} s^{-1}) (gs)

To monitor the internal water status of the plants, gs measurements were collected with a leaf porometer (Decagon brand) during noon (11:00-13:00) on leaves that are totally sun facing and newly formed in three plants from each plot. Measurements were taken monthly starting about 3 months after planting.

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Leaf water potential (bar) (ΨL)

To find out the effects of applications on the leaf water status, ΨL analyses were start about 3 months after planting, measurements were carried out with a portable pressure chamber equipment from PMS Instrument Company (Model 615) in the middle of the day (between 12:00-13:30) and monthly. Each replication consisted of five fully developed sun-facing leaves, and the average of these values was used to determine the mid-day ΨL value.

Statistical analysis

The experiment was designed as three factorials completely randomized with irrigation regime, mulching color, and harvest dates (dap of 155th, 185th, 219th, 250th) with the exception of macronutrient analyses. In macro nutrition, used one harvest date (DAP 250) with the other factors. MP 5.0.1 was used to evaluate the acquired data (SAS Institute Inc., Cary, NC, USA). Least Significant Difference (LSD) tests with $*p \leq 0.05$ were employed to compare the groups.

Results and discussion

Irrigation management

The plant water requirements were only fulfilled by irrigation water; precipitation and runoff were eliminated. All applications received the same amount of water from the time the seedlings were planted until January 23, 2018 (179 mm). All mulch applications on IR100 and IR50 received a total of 218 and 109 mm of water from January 23, 2018 until the end of the study, respectively. In addition, between January 23 and June 19, 490 mm Class A pan evaporation were recorded for 142 days, and a total of 29 irrigations were carried out across all applications during that time. Previous researches on strawberries have indicated a wide range of irrigation water use, ranging from 250 mm to 825 mm (Yuan et al., 2004; Kumar and Dey, 2011; Kapur et al., 2018; Celiktopuz et al., 2021; Sarıdaş et al., 2021). Many factors, including growing conditions, air temperature, growing season, plant pan coefficient (Kcp), and air humidity, might contribute to this difference.

Photosynthetic pigments

Chlorophyll, the most prevalent pigment in photosynthesis and a significant factor in plant development, was measured in strawberry plants under varied color mulch and irrigation regimes in the Fortuna strawberry variety. Different color mulch applications had no detectable impact on total chlorophyll, chlorophyll a, chlorophyll b, chlorophyll a/b, and carotenoids (*Table 1*). Santin et al. (2017) showed, in an experiment using black, silver, and mulch-free applications, that different color mulch treatments had no impact on chlorophyll in the Camarosa strawberry cultivar. Their results are consistent with our own. On the other hand, the Camino cultivar was identified as being impacted in the same study. In this regard, it has been shown that the amount of chlorophyll in strawberries reacts to mulch colors differently according on the variety, with reactions being lower in types with large leaf areas and higher in types with tiny leaf areas (Oliveira and Scivittaro, 2011). Additionally, parallel findings to our study were discovered in several species. In a study conducted in Japan utilizing soybean straw, plastic mulch, grass, and paper, Kader

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et al. (2017) found that different cover materials had no impact on the plant's chlorophyll concentration. When periodically evaluated, all the aforementioned parameters showed statistically significant variations. In March (185 DAP), the highest amount of chlorophyll features was discovered. This was followed by a decline in the weeks that followed. Since the N values for the same period were high in the current study, it is anticipated that there may be a strong correlation between chlorophyll and N concentration, as indicated in Gholizadeh et al. (2017). Total chlorophyll, chlorophyll a, chlorophyll a/b, and carotenoid levels all sharply decreased under IR50 irrigation regimes (water stress). Furthermore, significant declines in chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid content are observed as the level of water stress increases; particularly from dap 185 through the end of the study. Sarıdaş et al. (2021) indicated that water stress has a negative impact on yield. Each of these pigments plays a part in the photosynthetic process, which influences yield. Therefore, the breakdown of these pigments may be a contributing factor in the decreased yield. Similar to this, Ghaderi and Siosemardeh (2011) discovered that water stress significantly reduced chlorophyll contents. In greenhouse research of the Salut strawberry variety, Klamkowski and Treder (2006) discovered that a lack of water changes the characteristics of chlorophyll, causing photosynthesis to be lowered and plant growth to be disrupted. Additionally, Yosefi et al. (2020) claimed that water stress significantly lowers the carotenoid concentration. It is believed that plants should attempt to maintain the viability of their photosynthetic systems by adjusting to stressful environments and reducing their chlorophyll content to prevent phytoinhibition. In reality, many studies have shown that plants limit their photosynthetic pigments as a way to protection against photoinhibition and photodynamic damage (Karataş et al., 2014). In light of these findings, it is crucial for farmers to exercise caution when calculating irrigation water levels to maintain an effective photosynthetic system and ensure optimal plant growth and yield. Proper irrigation management can help mitigate the negative effects of water stress on photosynthetic pigments and ultimately improve strawberry crop productivity. Understanding the intricate relationship between water availability and photosynthetic pigments is vital for sustainable strawberry cultivation practices.

Table 1. *The impacts of different mulch types on photosynthetic pigments at various irrigation levels during the active growth period*

	Treatments	Irrigation levels	DAP				Treatments means	Treatments × Irr"
			155	185	219	250		
Total chlorophyll	No mulch	100	15.2	18.9	7.9	6.6	11.6	12.2
		50	13.9	17.3	7.2	5.7		11.0
	Transparent	100	16.8	19.8	8.6	6.3	12.2	12.9
		50	14.7	18.2	7.6	5.5		11.5
	Black	100	15.4	19.2	8.9	6.6	11.9	12.6
		50	14.9	18.6	6.0	6.2		11.4
	Silver	100	15.4	21.6	7.6	5.9	12.1	12.6
		50	12.7	21.7	6.1	5.8		11.6
Mean of dap			*14.9 B*	*19.4 A*	*7.5 C*	*6.1 D*		
Irrigation Means 100							12.5 A	
50							11.4 B	
$LSD_{i*} = 0.81$ $LSD_{d*} = 1.14$								

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Chlorophyll a	No mulch	100	10.5	12.5	2.6	2.5	6.8	7.0
		50	9.6	11.7	2.8	2.2		6.6
	Transparent	100	11.6	13.4	3.4	2.5	7.1	7.7
		50	9.9	11.2	2.9	2.2		6.6
	Black	100	10.5	10.3	3.8	2.7	6.5	6.8
		50	10.2	9.9	2.6	2.4		6.3
	Silver	100	9.4	14.4	2.9	2.3	7.0	7.3
		50	8.6	13.9	2.4	2.3		6.8
Mean of dap			*10.1 B*	*12.2 A*	*2.92 C*	*2.38 C*		
Mean of irrigation 100 50			7.20 A 6.56 B					
LSD_{i*} = 0.54 LSD_{d*} = 1.09 LSD_{txd*} = 1.54								
Chlorophyll b	No mulch	100	3.16	4.14	0.83	0.46	2.1	2.2
		50	2.88	3.48	1.00	0.44		1.9
	Transparent	100	3.47	4.01	0.94	0.57	2.2	2.2
		50	3.13	3.50	1.21	0.39		2.1
	Black	100	3.25	3.06	1.18	0.59	1.9	2.0
		50	2.99	3.12	0.78	0.71		1.9
	Silver	100	2.66	4.49	0.82	0.34	2.2	2.1
		50	2.66	5.13	0.73	0.56		2.3
Mean of dap			*3.03 B*	*3.87 A*	*0.94 C*	*0.51 D*		
Mean of irrigation 100 50			2.13 2.05					
LSD_{d*} = 0.29 LSD_{txd*} = 0.58								
Chlorophyll a/b	No mulch	100	3.30 fgh	3.06 gh	3.09 gh	5.51 b	3.71	3.74 B
		50	3.34 fgh	3.36 fgh	2.79 gh	5.21 bc		3.68 B
	Transparent	100	3.34 fgh	3.38 fgh	3.39 fgh	4.46 cde	3.65	3.64 B
		50	3.17 gh	3.21 gh	2.56 h	5.70 b		3.66 B
	Black	100	3.26 fgh	3.37 fgh	3.26 gh	4.49 cd	3.50	3.59 B
		50	3.42 fgh	3.19 gh	3.53 efg	3.54 efg		3.42 B
	Silver	100	3.54 efg	3.21 gh	3.61 d-g	7.03 a	3.82	4.35 A
		50	3.28 fgh	2.73 gh	2.96 gh	4.17 def		3.29 B
Mean of dap			*3.33 B*	*3.19 B*	*3.14 B*	*5.01 A*		
Mean of irrigation 100 50			3.83 A 3.51 B					
LSD_{i*} = 0.24 LSD_{d*} = 0.34 LSD_{txi*} = 1.65 LSD_{txd*} = 0.67 LSD_{txixd*} = 0.95								
Carotenoid	No mulch	100	3.43	3.77	1.15	0.98	2.27	2.33
		50	2.92	3.76	1.16	1.02		2.21
	Transparent	100	3.74	3.83	1.43	0.95	2.34	2.49
		50	3.15	3.52	1.18	0.91		2.19
	Black	100	3.45	3.55	1.41	1.08	2.29	2.37
		50	3.33	3.58	1.00	0.95		2.21
	Silver	100	3.58	4.51	1.18	0.84	2.43	2.53
		50	3.20	4.32	0.95	0.83		2.33
Mean of dap			*3.35B*	*3.85A*	*1.18C*	*0.95D*		
Mean of irrigation 100 50			2.43 A 2.24 B					
LSD_{i*} = 0.15 LSD_{d*} = 0.26 LSD_{txd*} = 0.42								

Differences between the means were showed with different letters, * $p < 0.05$

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Fruit N, P, and K concentration

Numerous studies have demonstrated that a variety of nutrients can affect the quality of fruits either directly or indirectly (Nestby et al., 2005; Tagliavini et al., 2005). The most crucial aspect is that each element's critical and ideal levels, as well as their interactions with one another, must be properly understood in order to yield the highest quality fruits (Nestby et al., 2005). While Tagliavini et al. (2005) asserted that the fruits require N particularly during the ripening period, and that P is one of the nutrients that moves from the leaves to the fruits during the ripening period, Hakala et al. (2003) claimed that potassium is the most important element in the strawberry fruit. N, P, and K in fruit were evaluated at 250 Dap (May), the prime harvesting period, in order to demonstrate the cumulative effects of all applications. The macro element concentrations of the fruit changed at various levels when different color mulch applications and two different irrigation levels were used (*Table 2*). In the study, N ranged from 0.64% - 0.95%, P 0.14% - 0.23%, K 1.29% - 1.84%, and the averages were found 0.76%, 0.19%, 1.62%, respectively. Our results generally accordance with Sharma et al. (2006) who discovered that the N, P, and K averages of different strawberry cultivars were 0.89%, 0.17%, and 1.57%, respectively, while Celiktopuz et al. (2021) found 0.97%, 0.26%, and 2.08%, respectively, under the different irrigation regime at various strawberry cultivars during two growing seasons. Fruit K concentrations were reported to be between 1.55 and 2.53% by Hakala et al. (2003). Similar studies have found that minor variations can be attributed to the strawberry variety used, fertilizations, weather patterns, and preferred irrigation water levels. It has been demonstrated that applying mulch, regardless of color, significantly improves P and K concentrations as compared to not applying mulch. In support of this, Kumar and Dey (2011) found that applying mulch improved plant nutrient uptake by 179%, and Kırnak et al. (2001) mulching mitigate the adverse effects of Water stress on N, P and K. While applying black or silver mulch significantly increased the K content, applying transparent mulch had little impact. Applications of black and silver mulch were discovered to be superior to alternative options when N, P, and K were taken into account together. The greatest values for N, P, and K were obtained by the Black × IR100 interaction, even though the mulch × irrigation interaction was statistically negligible. This circumstance has been linked to the fact that physical factors such as soil temperature and humidity influence nutrient uptake. It is thought that the black colored mulch increased nutrient uptake as the soil temperature rises. This statement can be explained by the fact that black-colored mulch materials have a higher light absorption tendency compared to other colors, leading to a more efficient shading effect. Due to their high light absorption and low albedo, black mulch materials can absorb more light and transmit it to the soil underneath, potentially affecting the microclimate around the plants. In addition to this point of view, Kumar and Dey (2011) claimed that irrigation techniques and mulching had both positive and significant effects on nutrient uptakes (N, P, and K). They reported, also, higher P and K may be associated with increased soil water moisture and improved root system. Fruit macro element concentration was significantly reduced due to water stress. Many researchers explained this situation that shown to reduce transpiration and limit stomatal openings (Silva et al., 2004), limit nutrient transport from roots to fruits, and decrease root water and nutrient uptake power during water stress (Hu and Schmidhalter, 2005). Under various climatic conditions, low water concentration is a factor that inhibits the way that nutrients spread throughout the plant (Silva et al., 2011). Keutgen and Pawelzik (2008)

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claim that water stress restricted fruit development, which in turn decreased nutrient concentrations and fruit quality during the fruit growth period. This might be a sign of lower biomass due to water stress, which would be the opposite of the higher nutritional concentration in the fruits. Furthermore, Perin et al. (2019) demonstrated that the Camarosa strawberry cultivar’s fruit K concentration reduced under IR 70 and IR50 irrigation levels as compared to control circumstances, and K concentration ranging from 1.36% to 1.50%. These results demonstrated a clear correlation between the amount of water applied and the nutritional state of the plant as well as physiological activities like transpiration and nutrient delivery. Consequently, a key element in getting the best output and fruit quality in strawberry cultivation is the amount of water used.

Table 2. *The impacts of different mulch types on macro elements at various irrigation levels during the efficient harvesting period*

Fruit	Irrigation levels	Treatments				
		No mulch	**Transparent**	**Black**	**Silver**	**Mean of irrigation**
N (%)	50	0.65	0.64	0.74	0.72	0.69 B
	100	0.68	0.74	0.95	0.93	0.82 A
Mean of mulch		*0.67 B*	*0.69 B*	*0.84 A*	*0.82 A*	
LSD_i* = 0.053 LSD_t* = 0.076						
P (%)	50	0.14	0.17	0.19	0.19	0.17 B
	100	0.16	0.22	0.23	0.23	0.21 A
Mean of mulch		*0.15 B*	*0.20 A*	*0.21 A*	*0.21 A*	
LSD_i* = 0.013 LSD_t* = 0.0177						
K (%)	50	1.29	1.49	1.62	1.60	1.50 B
	100	1.54	1.77	1.84	1.81	1.74 A
Mean of mulch		*1.42 C*	*1.64 B*	*1.73 A*	*1.71 A*	
LSD_i* = 0.046 LSD_t* = 0.064						

Differences between the means were showed with different letters, * $p < 0.05$

Physiologic observation

The ΨL and gs results of ‘Fortuna’ were shown in *Table 3*, where during the active development period under two different watering amounts and different colored mulch types. These parameters were measured monthly in the middle of the day prior to irrigation applications.

When compared to IR100, it has been discovered that IR50 dramatically affects the ΨL (*Table 3*). As soil water decreases under water shortage conditions, it is expected that ΨL and gs values will suffer. Understanding the stress physiology of strawberry plants requires monitoring at changes in ΨL and gs in plants under water stress. Similar findings were indicated by Klamkowski and Treder (2006), Grant et al. (2010), and Kapur et al. (2018) have all observed decreases in ΨL in strawberry during water stress. Regarding the mulch applications, silver mulch had the significantly highest ΨL (-14.8 bar) and followed by black, transparent and unmulched applications with -16.7, -17.3 and -19.4 bar, respectively. Thereby, silver mulch save more water than black, transparent and unmulched conditions with ratios of 12.8%, 16.9% and 31%, respectively. In our study, we found that mulch color had a notable impact on the

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microclimate surrounding the strawberry plants. Among the four mulch colors tested, the silver mulch application generally yielded the most favorable results. The silver mulch, characterized by its higher albedo value, effectively reflected a significant portion of solar radiation, contributing to relatively lower soil and air temperatures in the immediate vicinity of the plants. In contrast, the black mulch, with its lower albedo and higher solar radiation absorption, led to elevated temperatures in the microenvironment. In term of active harvest dates (February-May), ΨL values sharply decreased due to higher temperature and cumulative effects of stress conditions. Interaction of mulch and irrigation had significantly influenced ΨL value. While the highest ΨL value was obtained at Silver IR100 combination with -13.4 bar, the lowest was determined in unmulch × IR50 interaction as -20.3 bar. When the active periods in which the plants develop are compared, it was discovered that the water retaining capacity of the leaves significantly reduced over time.

Table 3. *The effects of mulch type on Lwp and gs at different irrigation levels during the active growth period*

	Irrigation levels		Period				Mean of treatments	Treatment × irrigation
			February	**March**	**April**	**May**		
ΨL (bar)	No mulch	50	-14.6	-15.8	-24.7	-26.0	-19.4 D	-20.3 F
		100	-13.8	-14.9	-22.3	-23.2		-18.6 E
	Transparent	50	-13.4	-14.5	-22.3	-23.0	-17.3 C	-18.3 E
		100	-12.7	-13.4	-19.3	-19.7		-16.3 C
	Black	50	-13.2	-14.2	-21.5	-22.3	-16.7 B	-17.8 D
		100	-12.1	-12.8	-18.1	-19.0		-15.5 B
	Silver	50	-13.0	-13.9	-18.1	-20.0	-14.8 A	-16.3 C
		100	-11.2	-12.1	-14.5	-15.7		-13.4 A
Mean of period			-13.0 A	-13.9 B	-20.1 C	-21.1 D		
Mean of irrigation			100	-15.9 A				
			50	-18.2 B				
LSD_t* = 0.32 LSD_i* = 0.22 LSD_p* = 0.32 LSD_{ixp}* = 0.45 LSD_{txi}* = 0.45 LSD_{txp}* = 0.64								
gs (μmol·m^{-2}·s^{-1})	No mulch	50	410.0	379.0	354.7	352.0	434.2 C	373.9 E
		100	528.0	495.7	482.7	471.3		494.4 C
	Transparent	50	450.7	408.7	415.0	407.0	509.7 B	420.3 D
		100	592.3	601.0	599.3	603.3		599.0 B
	Black	50	473.3	433.0	425.3	420.0	526.9 B	437.9 D
		100	604.7	629.0	613.7	616.7		616.0AB
	Silver	50	514.3	459.0	465.7	462.0	556.3 A	475.3 C
		100	625.7	641.7	640.3	642.0		637.4 A
Mean of dap			524.9 A	505.9AB	499.6 B	496.8 B		
Mean of irrigation			100	587 A				
			50	427 B				
LSD_{t*} = 19.5 LSD_{i*} = 13.8 LSD_{p*} = 19.5 LSD_{ixp*} = 27.6 LSD_{txi*} = 27.6								

Differences between the means were showed with different letters, *$p < 0.05$

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One of a plant’s earliest responses to a drop in soil water is to reduce stomatal conductance (Klamkowski, 2015). Stoma: it controls the transfer of gases between the leaves and the atmosphere, as well as the flow of plant nutrients and water between the leaves and the soil. They therefore play a significant role in the systems that control how plants use water (Spinelli, 2010). In the current study, it was found that plants with adequate irrigation had significantly higher stomatal conductivities than plants with insufficient irrigation (*Table 3*). Fully irrigated plants had 37% higher gs when compared to plants that received limited irrigation, and these changes were statistically significant. In the case of water restriction, the Fortuna strawberry cultivar lowered gs, and others (Ghaderi and, Siosemardeh, 2011; Grant et al., 2010; Klamkowksi et al., 2015) reported similar results. It was discovered that the differences between the gs values of several color varieties of mulch were statistically significant. While the silver mulch type was discovered to have had the best values, the black and transparent colored matches were found to be in the same important group and came in second. No-mulch applications, on the other hand, were at the bottom of the priority list, falling behind other applications and attracting attention as the application that was most affected by water stress. Similar to irrigation regimes, different types of mulching had a big impact on strawberry plants’ gs values. Besides, mulching application improved gs value of strawberry plant by different level, in this content, silver, black and transparent is increased 17.4%, 21.3%, and 28.1% ratios compared with unmulched condition. As Kendrick and Kronenberg (2012) emphasized, the reason for this difference can be explained as the photoreceptors in stoma cells detect certain wavelengths of light and the stomata activated by such receptors increase or decrease according to the light intensity. For this reason, it has been determined that the stomatal conductivity values of different colored mulches used in the study differ due to their ability to reflect different wavelengths. Regarding to the harvest dates, similar to the ΨL values, gs values were significant decreased. However, this was less sensitive to the environmental condition in as much as ΨL. February had the highest gs of 524.9 μmol m^{-2} s^{-1}, while the May had the lowest value of 496.8 μmol m^{-2} s^{-1}. The variations in gs caused by the mulch × irrigation interaction were found to be statistically significant. While silver × IR100 application with 637.4 μmol m^{-2} s^{-1} produced the highest gs, No mulch × IR50 application with 373.9 μmol m^{-2} s^{-1} produced the lowest gs.

The physiological observations in this study demonstrate the significant influence of irrigation levels and mulch colors on ΨL and gs in strawberry plants. The results highlight the importance of proper irrigation management and mulch selection to optimize water use efficiency and create a favorable microclimate for strawberry cultivation. The findings also emphasize the role of different mulch colors in influencing the plant’s response to water stress and environmental conditions. By understanding and considering these physiological parameters, farmers and researchers can make informed decisions to enhance plant performance and fruit quality in strawberry cultivation under varying environmental conditions.

Conclusions

The global population has risen over the recent decade. Scientists are focusing their efforts on creating new strategies for making optimal use of natural resources, such as water and soil conservation. We attempted to determine the influence of irrigation regimes and cover materials on some factors that affect fruit quality and production in

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our research. Reduced water and unmulching conditions have a negative impact on all of these characteristics. Total chlorophyll (10%), chlorophyll a (10%), and carotenoid (9%), chlorophyll b (4%), ΨL (14%), gs (37%), and N, P, and K concentrations were all reduced by 19%, 24%, and 16%, respectively, due to insufficient irrigation. Plants growing in silver mulch showed higher ΨL and gs than those grown in unmulched, transparent, or black mulch, with 31%, 17%, and 13%, and 28%, 9%, and 6% ratios, respectively. Overall, our findings suggest that opting for silver mulch × Ir100 may provide a more favorable microclimate for strawberry cultivation, potentially enhancing photosynthetic pigments, physiological parameters, and macronutrient concentrations compared to the other mulch colors tested. These results highlight the significance of mulch color selection in optimizing agricultural practices and achieving better plant performance.

REFERENCES

[1] Barrales-Dominguez, J. S., Alejo-Santiago, G. (2002): Growth of potato plants cv. Atlantic during the winter, harvest residue mulch. – Revista Chapingo, Serie Horticultura 8(1): 39-48.

[2] Celiktopuz, E., Kapur, B., Sarıdas, M. A., Paydas Kargı, S. (2021): Response of strawberry fruit and leaf nutrient concentrations to the application of irrigation levels and a biostimulant. – J. Plant Nutr. 44(2): 153-165. DOI: 10.1080/01904167.2020.1806310.

[3] Estes, E. A., Skroch, W. A., Konsler, T. R., Shoemaker, P. B., Sorensen, K. A. (1985): Net economic values of eight soil management practices used in stake tomato production. – Jour. of Amer. Soc. Hort. Sci. 110(6): 812-816.

[4] Ghaderi, N., Siosemardeh, A. (2011): Response to drought stress of two strawberry cultivars (cv. Kurdistan and Selva). – Hortic Environ Biotechnol. 52: 6-12. DOI: 10.1007/s13580-011-0019-6.

[5] Gholizadeh, A., Saberioon, M., Boruvaka, L., Wayayok, A., Soom, M. A. M. (2017): Leaf chlorophyll and nitrogen dynamics and their relationship to lowland rice yield for site-specific paddy management. – Inf. Process. Agric. 4: 259-268. DOI: 10.1016/j.inpa.2017.08.002.

[6] Grant, O. M., Johnson, A. W., Davies, M. J., James, C. M., Simpson, D. W. (2010): Physiological and morphological diversity of cultivated strawberry (Fragaria×ananassa) in response to water deficit. – Environ. Exp. Bot. 68: 264-272. DOI: 10.1016/j.envexpbot.2010.01.008.

[7] Hakala, M., Lapvetelainen, A., Huopalahti, R., Kallio, H., Tahvonen, R. (2003): Effects of varieties and cultivation conditions on the composition of strawberries. – J. Food. Compost. Anal. 16(1): 67-80. DOI: 10.1016/S0889-1575(02)00165-5.

[8] Hu, Y., Schmidhalter, U. (2005): Drought and salinity: a comparison of their effects on mineral nutrition of plants. – J. Plant. Nutr. Soil Sci. 168(4): 541-549. DOI: 10.1002/jpln.200420516.

[9] Kacar, B. (1972): Bitki ve Toprağın Kimyasal Analizleri, II. Bitki analizleri. – Ankara Üniversitesi Ziraat Fakültesi Yayınları, No. 453 Press, Ankara, Turkey (in Turkish).

[10] Kader, M. A., Senge, M., Mojid, M. A., Nakamura, K. (2017): Mulching type-induced soil moisture and temperature regimes and water use efficiency of soybean under rain-fed condition in central Japan. – Int. Soil Water Conserv. Res. 68(3): 264-272. DOI: 10.1016/j.iswcr.2017.08.001.

[11] Kapur, B., Çeliktopuz, E., Sarıdaş, M. A., Paydaş Kargı, S. (2018): Irrigation regimes and bio-stimulant application effects on yield and morpho-physiological responses of strawberry. – Hortic. Sci. Technol. DOI: 10.12972/kjhst.20180031.

[12] Karataş, İ., Öztürk, L., Demir, Y., Ünlükara, A., Kurunç, A., Düzdemir, O. (2014): Alterations in antioxidant enzyme activities and proline concentration in pea leaves under long-term drought stress. – Toxicol. Ind. Health. 30(8): 693-700. DOI: 10.1177/0748233712462471.
[13] Kasperbauer, M. J. (2000): Strawberry yield over red versus black plastic mulch. – Crop Sci. 40(1): 171-174. DOI: 10.2135/cropsci2000.401171x.
[14] Kasperbauer, M. J., Hunt, P. G. (1998): Far-red light affects photosynthate allocation and yield of tomato over red mulch. – Crop Sci. 38(4): 970-974. DOI: 10.2135/cropsci1998.0011183X003800040015x.
[15] Kendrick, R. E., Kronenberg, G. H. (2012): Photomorphogenesis in Plants. – Springer Science & Business Media, Dordrecht.
[16] Keutgen, A. J., Pawelzik, E. (2008): Quality and nutritional value of strawberry fruit under long term salt stress. – Food Chem. 107(4): 1413-1420. DOI: 10.1016/j.foodchem.2007.09.071.
[17] Kırnak, H., Kaya, C., Higgs, D., Gercek, S. (2001): A long-term experiment to study the role of mulches in the physiology and macro-nutrition of strawberry grown under water stress. – Australian Journal of Agricultural Research 52(9): 937-943.
[18] Klamkowski, K., Treder, W. (2006): Morphological and physiological responses of strawberry plants to water stress. – Agric. Conspec. Sci. 71(4): 159-165. https://hrcak.srce.hr/7902.
[19] Klamkowski, K., Treder, W., Wojcik, K. (2015): Effects of long-term water stress on leaf gas exchange, growth and yield of three strawberry cultivars. – Acta Sci. Pol. Hortorum Cultus. 14(6): 55-65.
[20] Kumar, S., Dey, P. (2011): Effect of different mulches and irrigation methods on root growth, nutrient uptake, water use efficiency and yield of strawberry. – Sci Hort. 127(3): 318-324. DOI: 10.1016/j.scienta.2010.10.023.
[21] Liang, Y. L., Zhang, C. E., Guo, D. W. (2002): Mulch types and their benefit in cropland ecosystems on the loess plateau in China. – J. Plant Nutr. 25(5): 945-955. DOI: 10.1081/PLN-120003930.
[22] Lichtenthaler, H. K., Wellburn, A. R. (1983): Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. – Biochem. Soc. Trans. 11(5): 591-592. DOI: 10.1042/bst0110591.
[23] Loughrin, J. H., Kasberbauer, M. J. (2002): Aroma of fresh strawberries is enhanced by ripening overred versus black mulch. – J. Agric. Food Chem. 50(1): 161-165. DOI: 10.1021/jf010950j.
[24] Nestby, R., Lieten, F., Pivot, D., Raynal, Lacroix, C. Tagliavini, M. (2005): Influence of mineral nutrients on strawberry fruit quality and their accumulation in plant organs. – Int. J. Fruit Sci. 5(1): 139-156. DOI: 10.1300/J492v05n01_13.
[25] Oliveira, R. P., Scivittaro, W. B. (2011): Desempenho produtivo de cultivares de morangueiro. – Sci. Agrar. 12: 69-74.
[26] Perin, E. C., Messıas, R. D. S., Gallı, V., Borowskı, J. C., Souza, E. R. D., Avıla, L. O. D., Bamberg, A. L., Rombaldı, C. V. (2019): Mineral concentration and antioxidant compounds in strawberry fruit submitted to drought stress. – Food Sci. Technol. 39(suppl 1): 245-54. DOI: 10.1590/fst.09717.
[27] Santin, A., Villa, F., Paulus, D. (2017): Chlorophyll concentration in plants and fruit yield of strawberry plants grown on mulching. – Revista de Ciências Agroveterinárias, Lages 16(3): 262-268. DOI: 10.5965/223811711632017262.
[28] Sarıdaş, M. A., Kapur, B., Çeliktopuz, E., Şahiner, Y., Paydaş Kargı, S. (2021): Land productivity, irrigation water use efficiency and fruit quality under various plastic mulch colors and irrigation regimes of strawberry in the eastern Mediterranean region of Turkey. – Agric. Water Manag. 245: 106568. DOI: 10.1016/j.agwat.2020.106568.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2105_47814794

[29] Sharma, R. R., Singh, R. (2008): Fruit nutrient concentration and lipoxygenase activity in relation to the production of malformed and button berries in strawberry (Fragaria x ananassa Duch.). – Sci. Hortic. 119: 28-31. DOI: 10.1016/j.scienta.2008.07.002.

[30] Sharma, R. R., Krishna, H., Patel, V. B., Dahuja, A., Singh, R. (2006): Fruit calcium concentration and lipoxygenase activity in relation to albinism disorder in strawberry. – Sci. Hortic. 107(2): 150-154. DOI: 10.1016/j.scienta.2005.06.008.

[31] Silva, D. C. E., Nogueira, R. J. M. N., Da Silva, M. A., De Albuquerque, M. B. (2011): Drought stress and plant nutrition. – Plant Stress, Global Science Books 5(Special Issue 1): 32-41.

[32] Silva, E. C., Nogueira, R. J. M. C., Azevedo, Neto, A. D., Brito Cabral, E. L. (2004): Aspectos ecofisiológicos de dez espécies em uma área de caatinga no município de Cabaceiras, Paraíba, Brasil. – Iheringia, Série Botânica 59(2): 201-206. https://isb.emnuvens.com.br/iheringia/article/view/218.

[33] Spinelli, F., Fiori, G., Noferini, M., Sprocatti, M., Costa, G. (2010): A novel type of seaweed extract as a natural alternative to the use of iron chelates in strawberry production. – Sci. Hortic. 125: 63-269. DOI: 10.1016/j.scienta.2010.03.011.

[34] Tagliavini, M., Baldi, E., Lucchi, P., Antonelli, M., Sorrenti, G., Baruzzi, G., Faedi, W. (2005): Dynamics of nutrients uptake by strawberry plants (Fragaria x Ananassa Dutch.) grown in soil and soilless culture. – Eur J Agron. 23: 15-25. DOI: 10.1016/j.eja.2004.09.002.

[35] Yosefı, A., Mozafari, A. A., Javadi, T. (2020): Jasmonic acid improved in vitro strawberry (Fragaria×ananassa Duch.) resistance to PEG-induced water stress. – Plant Cell Tissue Organ Cult. 142: 549-558. DOI: 10.1007/s11240-020-01880-9.

[36] Yuan, B. Z., Sun, J., Nishiyama, S. (2004): Effect of drip irrigation on strawberry growth and yield inside a plastic greenhouse. – Biosyst. Eng. 87: 237-245. DOI: 10.1016/j.biosystemseng.2003.10.01.

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