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Effects of subsurface drip irrigation and water stress on sesame seed color characteristics

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Abstract

Sesame seed color is an important criterion used in selection for marketing and variety development of the product. Although several studies have related seed color to biochemical composition, the effect of irrigation strategies on sesame seed color has not been investigated yet. The present study aimed to evaluate the effects of four irrigation levels (I1: 100%, I2: 70%, I3: 40% and I4: rainfed) applied by subsurface drip irrigation system at three different lateral depths (D1: 20 cm, D2: 30 cm and D3: 40 cm) on sesame seed color. The results show that sesame seeds grown under different irrigation levels showed significant differences in a*(red-green) and b* (yellow-blue) color parameters. Water level as the lateral depth of irrigation water increased, the color of sesame seeds lightened. Intensification was observed in the density and overall average color values at 30 cm lateral depth irrigation. Although the values and density are more scattered in the irrigations at 20 and 40 cm depth, an increase is observed in the L* color values obtained in the irrigations at 40 cm depth. In general, an increase was detected in the L* value with the lateral depth. When all the results were evaluated, it was determined that the lateral depth recommended in the study should be 40 cm and the irrigation level should be 70%.

Introduction

The annual global production of vegetable oils in Türkiye is approximately 1.2 billion tons, of which approximately 6.2 million tons consist of sesame (Sesamum indicum L.). Among oilseeds, sesame holds a prominent position in international trade, with an import volume of 2.5 million tons valued at 3.6 billion dollars and an export volume of 2.1 million tons valued at 3 billion dollars (FAO, 2023).

Seed color plays a critical role in consumer preference, marketability, and breeding programs. Various studies have demonstrated strong correlations between seed color and biochemical composition, with darker seeds typically exhibiting higher protein content and lighter seeds containing increased levels of palmitic and linoleic acids (Baydar et al., 1999; Beatrice et al., 2006). While previous research has extensively analyzed genetic and environmental influences on sesame seed color, little attention has been given to the effects of irrigation practices. The color of sesame seeds is

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influenced by genotype, environment, and their interactions, resulting in significant variations (Pathak and Dixit 1992; Yol, 2011; Cui et al. 2021). The color of the seed coat is strongly associated with its biochemical composition, influencing both quality and nutritional value. Sesame seeds exhibit a wide range of colors, from white to black (Weiss, 2000), with color intensity affecting fatty acid profiles. As seed color transitions from dark to light, the proportions of palmitic and linoleic acids tend to increase, whereas stearic and oleic acid levels decrease (Beatrice et al. 2006). Additionally, darker-colored seeds generally contain higher protein content and lower oil content compared to lighter-colored seeds (Baydar et al. 1999). Drought is one of the most important abiotic environmental stresses affecting plant growth and reduces a significant portion of agricultural production, especially in arid and semiarid regions (Rahimi-Moghaddam et al., 2021). Despite the optimum drought tolerance of sesame, continuous and severe water deficit during the growing season can negatively affect plant growth and development and reduce qualitative and quantitative yield (Pandey et al., 2021). When plants are exposed to drought stress, they adopt different mechanisms to overcome the harmful effects of stress conditions (Abid et al., 2018; Deihimfard et al., 2023). Stressed plants cope with stress by assisting various defense mechanisms such as biochemical, physiological, and morphological changes (Oguz et al., 2022). In particular, plant defense mechanisms are largely controlled by genetic and environmental factors (Zou et al., 2021). Abid et al. (2018) investigated the physiological and biochemical response of wheat seedlings to water-limited conditions and found that drought stress reduced leaf water content, membrane stability, and photosynthetic activity. Eyni-Nargeseh et al. (2019) evaluated the effects of cessation of irrigation regime on rapeseed genotypes and concluded that rapeseed genotypes grown under drought stress conditions had lower RWC and higher proline content than those fully irrigated. Pourghasemian et al. (2020) investigated the effects of drought stress regimes on sesame and reported that CAT activity was significantly induced in plants exposed to drought stress conditions.

Water scarcity and irregular rainfall patterns pose significant challenges to global agricultural productivity, necessitating the adoption of efficient irrigation strategies. Subsurface drip irrigation (SDI) is an advanced method designed to optimize water use efficiency while minimizing evaporation and runoff. While sesame seed composition and color have been widely studied, the specific effects of irrigation practices on these traits remain unclear.

This study aims to fill this research gap by evaluating the impact of varying irrigation water levels and lateral depths on sesame seed color parameters (L*, a*, b*). We hypothesize that different irrigation levels will result in distinct color changes, affecting consumer preferences and marketability. By identifying optimal irrigation parameters that produce desirable seed colors, this study aims to guide breeding strategies that enhance both seed quality and market value, supporting growers in meeting market demands and improving profitability in international trade. In addition, the level of improvement in seed size and color, which are the most important marketing criteria, was determined by the amount of irrigation. While doing this, the inadequacy of our water resources, the physiology of the plant, different irrigation amounts and different lateral depths, and soil structure were taken into consideration.

Material and Methods

Experimental area and climatic conditions

In 2020, the experiment was conducted in Aksu district, Antalya province, Türkiye. Table 1 shows the meteorological data, including temperature, precipitation, and relative humidity, where collected from the experimental site, along with the long-term averages from 2009 to 2018. Meteorological data were taken at the meteorological station in the experimental area. The experimental field did not receive sufficient seasonal precipitation following planting. The experimental site in 2020 experienced a drier climate compared to the long-term average. While the temperatures remained relatively consistent, with average monthly temperatures ranging from 20.9°C to 28.9°C, the precipitation levels were significantly lower. During the crucial summer months of June, July, and August, no rainfall was recorded, deviating sharply from the historical average of 13.0 mm, 3.0 mm, and 2.0 mm, respectively. This prolonged dry spell, coupled with the high temperatures, likely created stressful conditions for sesame growth and development.

Table 1. Comparison of 2020 Temperature and Precipitation Data with Long-Term Averages (2009–2018).

Months	Temperature (ºC)		Precipitation (mm)		Relative humidity (%)	
	2009-2018	2020	2009-2018	2020	2009-2018	2020
May	20.9	28.9	53.0	1.7	69.9	68.6
June	25.5	23.7	13.0	-	64.8	70.7
July	28.5	28.6	3.0	-	63.5	70.4
August	28.3	28.3	2.0	-	66.0	66.2
September	24.9	25.8	22.0	12.0	67.0	69.0

Experimental soil properties

The soils of the experimental area have a clayey loam texture between 0-60 cm and a loam texture between 60-120 cm. The lime content varies between 23.7-25.6% and it was determined that they are in the very calcareous soil class where the lime content decreases relatively towards the lower layers. The electrical conductivity of the experimental area soils varies between 0.10-0.15 dS m^{-1} (salt-free) and the pH content varies between 8.3-8.4 (moderately alkaline). Field capacity values were calculated as 23.5, 23.4, 23.1 and 23.2 g g-1 for 0-30, 30-60, 60-90 and 90-120 cm, respectively, while the wilting point values were calculated as 10.8, 11.1, 11.7 and 10.8 g g^{-1}. The bulk density values ranged between 1.31-1.43 g cm^{-3}, and it was determined that the bulk density values increased towards the lower layers.

Treatments and experimental design

The research was carried out in the application area of the Western Mediterranean Agricultural Research Institute Aksu Campus in a field trial with 3 replicates in a total of 36 plots in a 2-year period as a gravel trial in a split plot design in randomized blocks. In the study, different lateral depths were sub-factor subjects (20, 30 and 40 cm) and different water levels (100%, 70%, 40% and rain-based production) were the main factor subjects. In the experiment, the plot sizes were selected as 6.8 x 7.7 m (52 m^2) in planting and 3.5 x 4.7 m (16.45 m^2) in harvesting.

Planting and cultural operations

In the spring, the soil was tilled with a plow, and the experimental area was cleaned of existing weeds. Before planting, the seedbed was prepared by disc harrows and coulters. The installation of the YAD irrigation system was completed before planting. According to the results of the fertility analysis of the experimental area soils in the laboratory, a 10 kg da^{-1} N 109 and 6 kg da^{-1} P_2O_5 fertilization program was applied to the experimental area. The seeds were planted in rows with a 70 cm row spacing and 10 cm row spacing with a seeder on May 19, 2020. Harvesting was done on different dates. The thirsty subjects were harvested first. As the amount of water application increased, the vegetation and harvesting time of the plant increased. The harvest dates of the I1, I2, I3 and I4 subjects are September 28, September 23, September 16 and September 13, respectively.

Irrigation systems

In the subsurface drip irrigation system, fixed flow in-line Φ16 PE dripper pipes were used. Separate ball valves and water meters were placed in each plot to control irrigation water amounts. As a result of the evaluation of the infiltration test and dripper tests conducted in the trial area, a lateral pipeline was placed in each plant row. In addition, the dripper spacing in the system was determined as 30 cm and the dripper flow rate as 2.1 L h^{-1}. Laterals were placed in arcs formed by cleaning the traces opened with a chisel, 20, 30 and 40 cm below the soil surface. The main line and manifold pipes in the system were also placed in arcs opened in the trial area. Air discharge valves were mounted on the manifold outlets.

Soil water content measurement and irrigation

The volumetric water content in the soil profile was monitored with a neutron meter device. Neutronmeter measuring tubes were placed in the soil every 30 cm to a depth of 120 cm to measure the soil water content. The soil moisture below the root depth of 90 cm (90-120 cm) was monitored to determine whether there was deep infiltration. All plots were given outlet water with surface drip irrigation immediately after planting. The deficient moisture in all plots was equalized by bringing it to field capacity after emergence. When 40% of the suitable moisture was consumed, the subject irrigation applications were started. Before irrigation, soil samples were taken from 3 repeated points from all experimental plots and the deficient moisture values were calculated with the gravimetric method. When the deficient moisture reached 40% of the suitable moisture in all plots, the control plots were irrigated to field capacity with D1I1 = 100%, D2I1 = 100% and D3I1 = 100%, and the other plots were irrigated with the determined rates (70% and 40%). In calculating irrigation water, since the percentage of cover was below 35% when the first irrigation was made, the percentage of cover was accepted as 35%. When the percentage of cover (Pc) values exceeded 35%, the actual measured values were used in the calculation (Keller and Bliesner, 1990). The percentage of cover values was calculated as a result of measurements on the same 3 plants selected before each irrigation. This value was calculated by dividing the plant crown development by the planting distance (plant row spacing, 70 cm).

Color Measurements

Samples from the harvested plots were taken for color analysis. In determining the color class, the sesame seed coat color scale from the Sesame Collaboration Panel was used as a reference (Cui et al. 2021). Measurement parameters; illuminator setting is D65, observer angle is 2°C, and measurement aperture is 10 mm. Calibration is done on a white plate (Figure 1). Color measurements were conducted using a Minolta Spectrophotometer CM-5 (Figure 1). The seed color readings were recorded in the CIE L*a*b* color space (Rahimi et al. 2011; Özpolat 2021). This system allows for precise and quantitative assessment of seed color,

Figure 1. Color measurements using the Minolta Spectrophotometer CM-5 device.

providing valuable data for both quality control and breeding purposes. The CIE L*a*b* parameters, commonly employed in color measurement, represent three-dimensional color coordinates. The CIELAB color space, often referred to as Lab*, is a color model that defines color based on three color components: L*, a*, and b*. L* denotes lightness, ranging from 0 (black) to 100 (white). The a* axis represents the red-green color space, with positive values indicating red and negative values indicating green. The b* axis represents the yellow-blue color space, with positive values indicating yellow and negative values indicating blue.

Statistical Analysis

Analysis of variance (ANOVA) was performed to determine the effects of irrigation level and lateral depth on sesame seed color parameters (L, a and b*)**. When significant differences were observed, an LSD test was employed to identify homogeneous groups of means. Additionally, a correlation analysis was carried out to examine the nature and strength of relationships of relationships between treatments and color scale values. For significant correlations, linear and polynomial regression analyses were performed to quantify these relationships, resulting in the derivation of regression equations for color values exhibiting significant associations.

Results and Discussion

Applications started on June 4, 2020. 321, 229, 137 and 15 mm irrigation water was applied to the 20 cm lateral depth I1, I2, I3 and I4 trial subjects, respectively; 256, 184, 111 and 15 mm irrigation water was applied to the 30 cm lateral depth I1, I2, I3 and I4 trial subjects, respectively; 248, 178, 108 and 15 mm irrigation water was applied to the 40 cm lateral depth 173 I1, I2, I3 and I4 trial subjects, respectively. According to soil water budget calculations, ETc values of sesame plants varied between 141-390 mm.

Lightness (L) Variations

The L values, representing seed brightness, ranged from 61.80 to 64.51*. The highest L value (64.51)* was observed at the 30 cm lateral depth with the 100% irrigation level (I1), suggesting that higher water availability at an intermediate lateral depth enhances seed brightness. In contrast, the lowest L value (61.80)* was recorded at the 20 cm depth with the 40% irrigation level (I3), indicating that water stress combined with a shallow drip line may contribute to darker seed coloration.

Red-Green Axis (a) Trends

The a values, which represent the red-green color balance, exhibited minimal variation across treatments (8.51 to 9.06)**. The lowest a value (8.51) was recorded at the 30 cm lateral depth with the rainfed treatment (I4), indicating a slightly greener hue under water-limited conditions. Conversely, the highest a value (9.06)* was observed at the 40 cm depth with the rainfed treatment (I4), suggesting a tendency toward a redder hue when irrigation was withheld at deeper lateral depths.

Table 2. Sesame seed color values at the plot level

Irrigation levels (%)	Lateral depth (cm)	L*	a*	b*
I_1	20	62.07	8.59	22.25
I_2		62.69	8.73	22.49
I_3		61.80	8.99	22.37
I_4		63.38	8.94	24.57
I_1	30	64.51	8.67	25.18
I_2		63.18	8.93	23.67
I_3		62.93	8.97	24.09
I_4		63.03	8.51	25.33
I_1	40	63.66	8.61	23.54
I_2		63.05	8.87	22.96
I_3		63.39	8.90	23.67
I_4		62.53	9.06	24.26

Yellow-Blue Axis (b) Response

The b values, which reflect the yellow-blue spectrum, ranged from 22.25 to 25.33*. The highest b value (25.33)* was observed at the 30 cm lateral depth with rainfed conditions (I4), indicating greater yellow intensity under lower water availability. This suggests that water stress may enhance yellow pigmentation in sesame seeds. Conversely, the lowest b value (22.25)* was recorded at the 20 cm lateral depth with 100% irrigation (I1), signifying a less yellow and slightly cooler color under fully irrigated conditions.

No previous studies have been investigated the impact of varying irrigation water levels and lateral depths in drip irrigation systems on sesame seed color. Gölükcü, (2000) reported L, a*, and b* values of 58.88, 3.93, and 23.13, respectively, for sesame tahini color using a similar color measurement method. In sesame procurement for industrial use, Carbonell-Barrachina, (2009) recommended high L* values along with high seed coat separability percentages and suggested that a* and b* values should be low for the seed coat. Our study recommends irrigation treatments involving different water levels and lateral depths that lead to high L* values and low a* and b* values.

The results of the analysis of variance (ANOVA) evaluating the effects of irrigation level and lateral depth on sesame seed color parameters (L, a, and b*)** are presented in Table 3. The F-values and associated probability levels (p-values) indicate the statistical significance of these factors. . The F-values and associated probabilities indicate the significance of these factors. For lightness (L*), a significant difference was observed only between lateral depths ($p<0.05$). This suggests that changing the lateral depth had a noticeable impact on the lightness of the sesame seeds. However, neither the irrigation level nor the interaction between irrigation level and lateral depth had a significant effect on L*. Regarding the red-green axis (a),* only the irrigation level was found to have a highly significant effect ($p<0.01$). Neither lateral depth nor the interaction term was significant for the a* parameter. For the yellow-blue axis (b*), both irrigation level and lateral depth had highly significant effects ($p<0.01$). The interaction term, however, was not significant (Table 3).

Table 3. The F values and significance levels for the effects of irrigation levels and lateral depth on sesame seed color

	DF	L*	a*	b*
Replication	2	1.24	0.25	2.30
Irrigation level	3	0.95	6.07*	15.23**
Replication x Irrigation	6	0.53	0.49	0.79
Irrigation depth	2	4.06*	0.41	29.33**
Irrigation level x Irrigation depth	6	1.39	2.43	2.69

*: Difference at the significance level of $p<0.05$, **: Difference at the significance level of $p<0.01$.

The sesame seed color values for different irrigation levels and lateral depths are given in Table 4. In general, irrigation levels had a significant impact on the yellowness (b*) of the sesame seeds, while lateral depth influenced both the lightness (L*) and b*. These findings suggested that both irrigation management and the placement of the drip irrigation system can affect the overall color quality of sesame seeds.

No significant differences were observed in L* values among the various irrigation levels, indicating that the lightness of the seeds remained relatively consistent. Significant differences were detected in a* values ($p<0.05$). The 100% irrigation level resulted in a significantly lower a* value compared to the other treatments, suggesting a slightly greener hue. Rainfed level had a significantly higher b* value, indicating a more yellowish hue. The 70% and 40% irrigation levels had significantly lower b* values, suggesting a less yellow hue compared to the rainfed level (Table 4).

Table 4. The sesame seed color variation values and groupings under different irrigation depths and water levels

Treatments	Seed color classification ***		
Irrigation levels	L*	a*	b*
rainfed	63.19	8.89a	24.74a
40%	62.75	8.95a	23.35bc
70%	62.98	8.83a	23.127c
100%	63.45	8.69b	23.73b
LSD	ns	*	**
Lateral depth			
20 cm	63.42b	8.87	22.92c
30 cm	63.37a	8.82	24.63a
40 cm	62.48a	8.84	23.66b
LSD	*	ns	**

*: Difference at the significance level of p<0.05, **: Difference at the significance level of p<0.01, ns: not significant, ***: Values marked with the same letter in the same column are not significantly different.

Considering lateral depth, significant differences were observed in L* values (p<0.05). The 20 cm lateral depth resulted in significantly higher L* values, indicating a lighter seed color compared to the other depths. No significant differences were observed in a* values among the lateral depths, suggesting that the red-green hue remained relatively consistent. Significant differences were observed in b* values (p<0.01). The 30 cm lateral depth resulted in a significantly higher b* value, indicating a more yellowish hue. The 20 cm and 40 cm depths had significantly lower b* values, suggesting a less yellow hue compared to the 30 cm depth (Table 4).

The results of correlation analysis, which reveal the significance, direction, and strength of the relationships between irrigation water levels, lateral depth applications, and sesame seed color characteristics are given in Table 5. A high-probability relationship (95-99%) indicates a meaningful correlation, enabling the development of predictive models using regression analysis to predict future trends (Sayılğan, 2020). Overall, the correlation analysis suggests that lateral depth had a significant impact on the lightness of the sesame seeds, while irrigation water level had a minimal effect on color parameters. A significant negative correlation (-0.46) was found between the irrigation water level and the a* parameter. This indicates that as the irrigation water level increased (e.g., from 40% to 100%), the redness of the sesame seeds decreased, shifting the color towards a greener hue. A significant negative correlation (-0.36) was found between irrigation water level and the b* parameter. This indicates that as the irrigation water level increased, the yellowness of the sesame seeds decreased, resulting in a less vibrant yellow color.

The correlation analysis revealed a significant positive correlation between lateral depth and the L* parameter (r=0.37, p<0.05), suggesting that increased lateral depth (e.g., from 20 cm to 40 cm) led to higher lightness values in sesame seeds, resulting in a brighter seed color. In contrast, no significant correlation was observed between lateral depth and the b* and a* parameters, indicating that lateral depth had little to no impact on these particular color characteristics.

Table 5. The relationship between subsurface drip irrigation applications and changes in sesame seed color

	Replication	Irrigation Water Level	Lateral Depth (cm)	L*	a*	b*
Replication	1.00					
Water Level	0.00 ns	1.00				
Depth (cm)	-0.00 ns	0.00 ns	1.00			
L*	0.19 ns	0.10	0.37*	1.00		
a*	0.06 ns	-0.46*	-0.08 ns	-0.43*	1.00	
b*	0.02 ns	-0.36*	0.27 ns	0.59*	-0.12 ns	1.00

*: Difference at the significance level of p<0.05, **: Difference at the significance level of p<0.01. ns: not significant

The results implied that irrigation water levels can be a valuable tool to influence the color characteristics of sesame seeds. Lower water levels may lead to a more reddish and yellowish seed color, while higher water levels may result in a greener and less yellow seed color. While lateral depth can impact the lightness of the seeds, it does not appear to significantly affect the yellowness. Therefore, the focus should be on optimizing irrigation water levels to achieve desired seed color qualities.

Table 6. The regression analysis for the characteristics with identified correlations

Variable 1	Variable 2	Linear Regression					Polynomial regression				
		R^2	R^2	Mean Square Error	F	p	R^2	R^2	Mean Square Error	F	p
a*	Water Level	0.208	0.185	0.152	8.977	*	0.334	0.293	0.141	8.276	*
b*	Water Level	0.129	0.103	1.062	5.056	*	0.313	0.271	0.957	7.519	*
L*	Lateral Depth	0.139	0.113	0.927	5.496	*	0.197	0.149	0.908	4.072	*
a*	L*	0.183	0.159	0.154	7.657	*	0.183	0.134	0.157	3.716	*
b*	L*	0.353	0.334	0.915	18.576	**	0.364	0.326	0.921	9.467	*

Linear and quadratic polynomial regression analyses were employed to establish a robust model for predicting the relationship between the highly correlated variables of irrigation level and lateral depth and the L*, a*, and b* color values of sesame seeds (Table 6). Both linear and polynomial regression models for a* and b* values were significant ($p < 0.05$), indicating a strong relationship between irrigation water level and redness and yellowness. Higher irrigation water levels were associated with lower a* and b* values, suggesting a decrease in redness and yellowness.

The analysis reveals a significant negative correlation between irrigation water level and the a* parameter of sesame seeds. This implies that as the irrigation water level increases, the redness of the seeds decreases, shifting the color towards a greener hue. The data indicates a clustering of a* values within specific water level ranges. The 0% and 40% water levels exhibited higher a* values, suggesting a more consistent color profile within these groups. In contrast, the 70% and 100% water levels showed a narrower range of a* values, indicating a more uniform color distribution. The highest a* value was observed at the 40% water level,

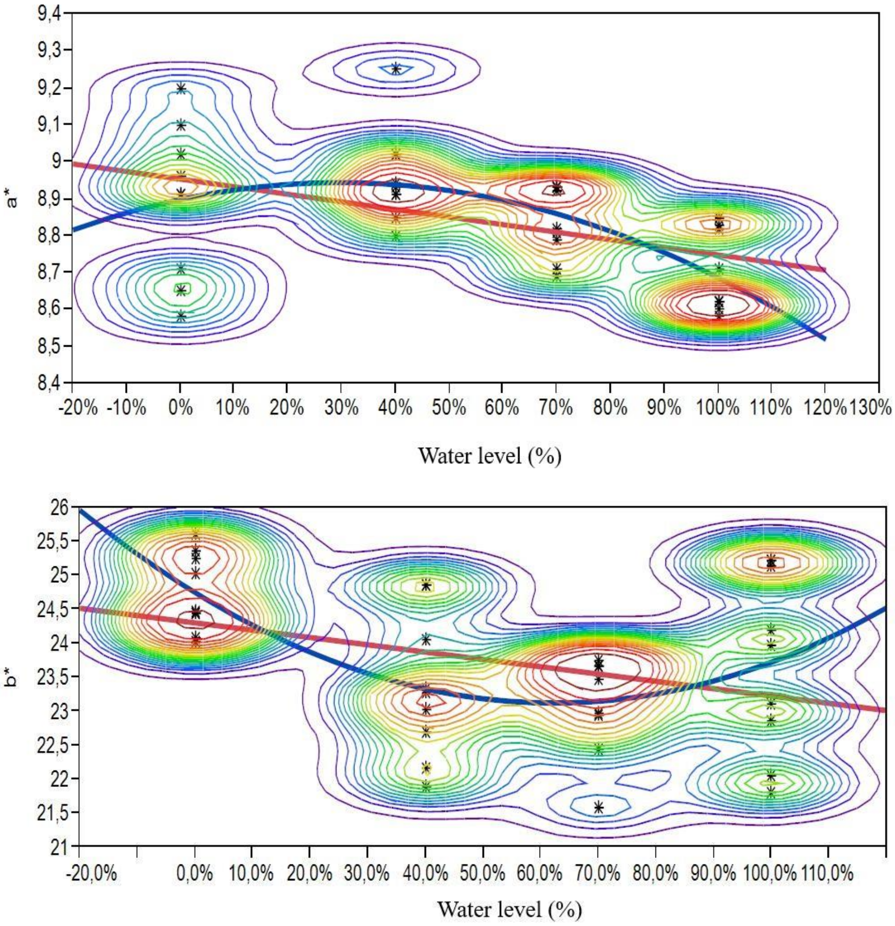
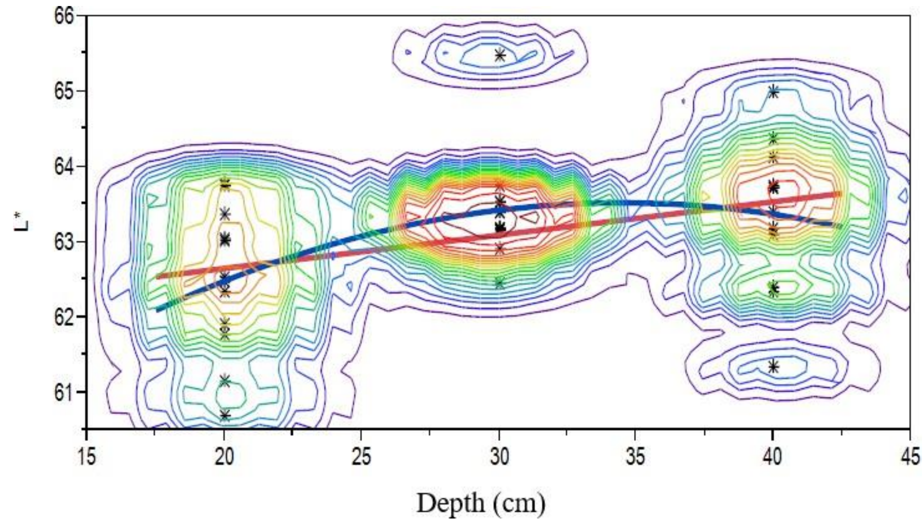


Figure 2. Change and density of a: a* and b: b* color scale values depending on irrigation level

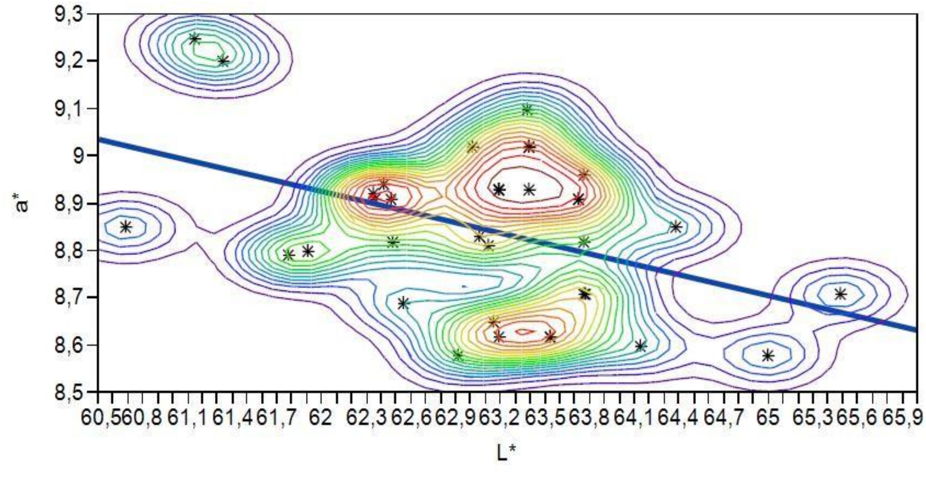
suggesting a relatively redder hue. As the water level increased beyond 40%, the a* values decreased, leading to a gradual shift towards a greener color. Both linear and polynomial regression models effectively captured the relationship between irrigation water level and the a* parameter. The linear regression equation "a* = 8.95 - 0.20 x Water Level" provides a simple approximation of the trend, while the quadratic regression equation "a* = 9.04 - 0.23 x Water Level - 0.52 x (Water Level - 0.52)²" offers a more precise fit by accounting for the curvature in the relationship (Figure 2).

The analysis revealed a significant positive correlation between lateral depth and the L* parameter of sesame seeds. The positive correlation implies that as the lateral depth increases, the lightness of the seeds increases, resulting in a brighter seed color. The data indicates a more concentrated distribution of L* values at the 30 cm lateral depth, suggesting a more uniform color profile within this group. At the 20 cm and 40 cm depths, the L* values were more dispersed, indicating greater variability in seed color. However, the 40 cm depth exhibited a trend towards higher L* values, suggesting a potential increase in lightness. Both linear and quadratic regression models effectively captured the relationship between lateral depth and the L* parameter. The linear regression equation "L* = 61.76 + 0.04 x Depth" provides a simple approximation of the trend, while the quadratic regression equation "L* = 62.09 + 0.04 x Depth - 0.0049 x (Depth - 30)²" offers a more precise fit by accounting for the curvature in the relationship (Figure 3).

The analysis highlighted a significant negative correlation between the a* and L* color parameters of sesame seeds. The negative correlation indicates that as



a



b

Figure 3. In the study; a: L* color scale value change and density depending on irrigation depth, b: a* color scale value change and density depending on grain color L* scale value

the lightness of the seeds increases, the redness decreases. The linear regression equation "a* = 13.48 - 0.07 x L*" effectively captures this negative linear relationship. The quadratic regression equation "a* = 13.48 - 0.07 x L* - 1.644 x 10^{-6} x (L* - 63.09)²" provides a more precise fit, although the linear model appears to be sufficient in this case (Figure 3). This finding suggests that there is a trade-off between lightness and redness in sesame seed color. As the seeds become lighter, the seeds tend to become less red and more towards a greenish hue.

The analysis revealed a highly significant positive correlation between the b* and L* color parameters of sesame seeds. This implies that as the lightness of the seeds increases, the yellowness also increases, resulting in a shift towards a whiter and more yellowish color. The linear regression equation "b* = -18.98 + 0.67 x L*" effectively captures this positive linear relationship. The quadratic regression model "b* = -17.83 + 0.66 x L* - 0.07 x (L* - 63.09)² " provides a more precise fit, although the linear model appears to be sufficient in this case. This finding suggests a strong association between lightness and yellowness in sesame seed color. As the seeds become lighter, they also tend to become more yellow.

Conclusion

The color of sesame seeds, a crucial quality criterion in breeding studies, was significantly influenced by variations in drip irrigation lateral depth and applied irrigation water levels. This study presents novel insights into these effects, demonstrating that both the irrigation water levels and lateral depth of the irrigation system significantly affect the color of sesame seeds, potentially influencing their market appeal and quality.

The findings indicated that seed color changes are directly linked to irrigation water amounts, suggesting that modifications in irrigation practices can affect seed quality. However, these changes generally occur in an undesirable direction concerning seed coloration. As the irrigation level increased, a shift in seed color was observed, transitioning from yellow to blue and from red to green. Similarly, an increase in lateral depth resulted in a change in seed color from dark to white, which was also considered undesirable for maintaining seed quality. Consequently, the results suggest that higher irrigation levels contribute to a decline in seed quality.

To optimize seed quality and color for both market acceptability and breeding purposes, a 70% irrigation water level combined with a 40 cm lateral depth in subsurface drip irrigation is recommended. This specific combination has been found to yield the most desirable seed color and overall quality.

Ethical Approval

We declare that the article is among the studies that do not require ethical approval.

Consent to Participate

Authors of the article declare their approval of participation.

Consent to Publish

The authors declare that the article will be published.

Authors Contributions

F.A.: Conducting fieldwork, collecting data, analyzing data and writing articles; **Ç.S.:** performing and evaluating statistical analyses; **F.A.V.:** Conducting and evaluating laboratory analyses; **Ö.Ö.:** Carrying out field work; **B.C.:** Analysis and evaluation of data.

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Conflicts of Interest

The authors of the article declared that there is no personal or financial conflict of interest within the scope of the study.

Availability of data and materials

For questions regarding the datasets, the corresponding author should be contacted.

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