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Determination of the Effects of Different Light Colors on the Germination and Development of Tomato Seeds

Mehmet Ali SARIKURT[1] , Abdullah SESSİZ[2]

[1]Department of Agricultural Machines and Technologies, Institute of Natural and Applied Science, University of Dicle, Diyarbakır, Türkiye
[2]Department of Agricultural Machines and Technologies, Faculty of Agriculture, University of Dicle, Diyarbakır, Türkiye

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Corresponding Author
Abdullah Sessiz
asessiz@dicle.edu.tr

Author ORCID
[1]https://orcid.org/0009-0001-2868-3398
[2]https://orcid.org/0000-0002-3883-0793

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Abstract

The main purpose of this study is to shorten the germination period of tomato seeds and fasten the germination rate and development. The artificial lighting and germination cabinet have been manufactured for this purpose. In this study, the germination and growth processes of three (Karacadağ, Lice, and Ahlat) local tomato varieties were examined. Instead of traditional light sources, four different LED (Light- Emitting Diodes) light colors (red, cool white, blue, and warm white) were used. For the germination and growth of the seeds, viols consisting of 6 x 12 cells were used. The tomato seeds were soaked two days before planting in the viols and left in a dark environment for four days. After the seeds emerged, they were transferred to a ligth environment, and the automatic timer was activated. The duration of light and dark exposure was also monitored. The plant was kept in a controlled growth environment with an automatic timer, providing 16 hours of light and 8 hours of darkness, with an average temperature of 25°C and relative humidity of 57%. After the seeds were planted, plant growth characteristics were assessed at 7 day intervals for a period of 42 days. In the study, measurements were taken for seedling length under different light colors over time, as well as plant root length, stem diameter, fresh and dry weight, leaf count, chlorophyll content, and leaves color (L, a, b) values. According to the research results, the effects of time, variety, and light color on the plant height development were statistically highly significant ($p<0.001$). Additionally, the differences between the measurement times, varieties, and LED light colors used as light sources were found to be highly significant ($p<0.001$). The shortest seedling length for all varieties was observed under red light, while the highest seedlings were achieved under daylight. Similarly, the shortest root length was recorded with red LED light for all varieties, whereas the best root development and length were observed under daylight conditions. The best root length values were measured in the Karacadağ and Lice varieties, which showed similar results. All varieties exhibited a decrease in SPAD (Chlorophyll measurrment device) values over time. The difference between them was found significant ($p<0.001$). The lowest root length values in all varieties were obtained in Karacadağ variety.

Keywords: Plant growth chamber, Germination Rooms, Tomato Seedlings, LED Light Sources, Artificial Lighting

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INTRODUCTION

Interdisciplinary methods based on innovative concepts that minimize resource consumption and environmental damage and significantly increase food yield and quality compared to existing classical plant production systems has begun to gain importance (Çağlayan and Ertekin, 2015; (Çağlayan and Ertekin, 2016; Lee et al., 2014; Fan et al., 2023; Zheng et al., 2021 Zheng et al, 2023). One of these production methods is artificial lighting plant production (Kato et al, 2010; Mitchell et al, 2020). This method, known as artificially lighting controlled environments (CEA), is an airtight facility used to grow plants under artificially controlled conditions, such as plant factories and growth chambers (Kozai et al, 2015; Saito et al, 2010; Zhang et al, 2018). These facilities are increasingly used for commercial leafy vegetable and fruit production, plant science research, and producing high-quality seedlings (Chintakovid et al, 2002; Fujiwara et al, 2004; Goto 2012; Kozai, 2013a;

Kozai, 2013b; Nicole et al, 2016). Compared to greenhouse or open field production, CEA is becoming increasingly important because it provides many other advantages such as precise control of the plant growth environment, optimization of environmental conditions, improvement of plant growth rate and obtaining high-quality plants for fresher vegetable production. CEA also provides benefits such as smooth and predictable growth and development of plant production, high product market value per unit of production area and short production period (Dreesen and Langhans, 1991). In addition, the artificial lighting system (ALS) offers various benefits such as increasing annual yield per unit area by keeping resource use efficiency at the highest level and high-quality plant production without the need for the use of pesticides (Yang et al, 2018; Zheng et al, 2021). Recently, LEDs have replaced fluorescent lamps as a popular light source in plant cultivation due to their high efficiency, low energy consumption, more compact structure, long life, various wavelengths and low thermal radiation emission among the sources used for artificial lighting purposes (Bourget , 2008; Johkan et al., 2010; Saito et al., 2010; Gupta and Jatothu , 2013; Tian et al., 2014; Bian et al, 2015; Singh et al, 2015; Gómez , 2015). Mitchell, 2015; Caglayan and Ertekin, 2016; Bantis et al., 2018;). The intensity, color and quality of light in LEDs are important for the growth, development, morphological and other physiological responses of plants (Fukuda et al, 2008; Li and Kubota, 2009).

The aim of vegetable production is to achieve earliness and offer the product to the market at an earlier price point. The first harvested products always yield a higher economic return, which adds value to the product in both domestic and foreign markets. For the producer, introducing the first product to the market brings economic profit, while consumers benefit from rapid access to the product. In the classical method, germination of small seeds, such as tomatoes, is difficult and requires a long processes. These seeds are influenced by factors such as climate conditions, environmental factors, and cultivation practices. The primary solution to this problem is creating environments that facilitate rapid and complete germination of the seeds. As a new method, germination chambers are used to provide fast germination and optimal growth environments. With germination chambers, all variables can be controlled, and the impact of sudden changes can be minimized compared to natural germination. Additionally, they contribute to greenhouse gas emissions, further exacerbating global warming and climate change. Also, this production method, conducted under controlled conditions, saves both time and space while also providing earliness for the product. Thanks to the use of germination chambers, it is possible to grow the desired product regardless of the season. This enables producers to earn more money by providing earliness at lower costs. Additionally, it will contribute to an increase in the number of seedling producers and the development of a new sector.

Previous studies have primarily focused on examining the impact of varying light intensities and wavelengths on the plant growth and development under natural sunlight. However, in this study, our primary aim was to shorten the germination period of tomato seeds and accelerate their development to achieve earliness. To achieve this, we constructed a germination cabinet and investigated the effects of different light colors on the germination and growth processes of tomato seeds under controlled conditions. LED light sources with varying colors were used instead of traditional light sources for the experiment. The seeds of three tomato varieties (Lice, Ahlat, and Karacadağ) widely grown in the Diyarbakır province, Turkey, and its surrounding region, were used in the study. Various factors, such as chlorophyll content, light intensity, color characteristics, plant height, root length, stem diameter, and dry matter, were examined under different light color conditions over time.

MATERIAL AND METHODS

Material

Plant Material

The plant material used in the study consisted of seeds from three local tomato varieties (Karacadağ, Lice, and Ahlat) widely grown in Diyarbakır, Turkey, and its surrounding areas. For the experiments, a custom-built 4-compartment shelf was constructed, measuring 150 cm in height, 75 cm in width, and 31 cm in depth, and covered with a rigid heat insulation board (Figure 1). LED (Ligth Emitting Diode) lights in four different colors (red, blue, cold white, and warm white (daylight)) were installed on the ceiling of the shelf compartments within the germination cabinet (Figure 1).

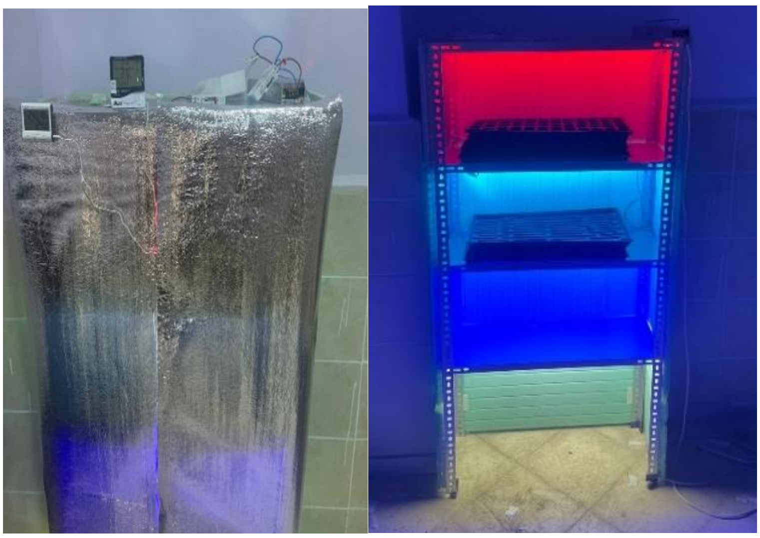

Figure 1. Growing cabin and LED lights.

To produce seedlings from seeds, seed germination and growth trays (violas) with 6 x 12 cells were used. The seeds of all three tomato varieties were planted at a depth of 1.00 cm, with each cell of the trays filled with approximately 1.00 cm of specially prepared soil (Perlite). A hygrometer and thermometer with a CD screen and clock display were used to monitor both indoor and outdoor temperature and relative humidity. An automatic timer was employed throughout the study, set to provide 16 hours of light and 8 hours of darkness (Wu et al., 2023)

Chlorophyll content was measured using fresh attached leaves with the SPAD meter. The Plant Chlorophyll Meter (SPAD) device, shown in Figure 2a, was used to measure the amount of chlorophyll in plant leaves, the luxmeter (Figure 2 b) device was used to measure light, and the CM11P digital colorimeter was used to measure the color of plant leaves (Figure 2c). Measurements were made directly from the upper surface of the leaves after the 3rd time period, when the surface of the leaves became measurable (Figure 2). Measurements were made in 3 replicates (Eliçin et al., 2022).

(a) (b) (c)

Figure 2. SPAD- Chlorophyll meter (a), Sensor light meter luxmeter (b), Color meter (c)

Digital calipers were used to determine plant diameters and rulers were used to measure their heights. Rulers were used to measure plant heights and root lengths, and digital calipers were used to measure diameters. A VIBRA brand electronic scale with 0.1 precision was used to determine the fresh weight of the seedlings and the weighing and moisture content of the dried seedlings, which were the materials used in the experiments. Oven drying method was used to determine the moisture content. For this, NÜVE FN 500 oven was used.

Method

Plant growth and seed production process

Tomato seeds were soaked 2 days before planting in the vials and left in a dark environment. After 2 days, seeds were placed in each well in the soil filled in the vials to ensure initial germination (Figure 3). After planting, all three varieties were placed on shelves divided into 4 different colors (Figure 3) in a way that would create 4 separate vials. The surroundings were completely covered with styrofoam and a heat and light proof insulated curtain that could be opened at the front for measurements (Figure 3). After planting, the vials placed in the growth environment were not exposed to light for 4 days. They were kept wet in a dark environment for 4 days and were expected to emerge and sprout. At the end of the 4th day, the seeds started to emerge. Germination images of the seed varieties used as trial material under different light colors are given separately for each color in Figure 3. In addition, a device that automatically measures the humidity, temperature and relative humidity of the environment was placed in the plant growth cabinet divided into different colors. After the seeds placed in the cabinet emerged, they were moved to a lighted environment and an automatic timer was activated. With this, the duration of light exposure and darkness were monitored. The plant was kept constant at 16 hours of light and 8 hours of dark, with an average temperature of 25 °C ± 5 °C and an average relative humidity of 55% ± 5% (Wu et al, 2023) (Figure 3).

The SPAD meter, luxmeter and colorimeter devices used in the measurements were brought into contact with the leaf (Wu et al, 2023). Measurements were made separately for the varieties on each shelf. Light levels for different light colors on each shelf in the cabin were checked and inspected, and the results were recorded.

Plant growth parameters and measurements

The seeds growth characteristics were examined at 7 day intervals for 6 weeks. The nutrient solution was used for better plant development. Five selected tomato plants were used for measurements of plant height and stem thickness. After the plants reached a sufficient growth stage, the measurement procedures were terminated. After this, the seedlings for each light color and tomato variety were removed from the growing trays used as seedlings, washed and cleaned from soil. Then, the seedling root lengths and stem diameters were measured using calipers (Wu et al., 2023).

After the last measurement, total height, root, branch, leaf count and moisture content measurements were made for five seedlings taken for each variety. Measurements were made from the middle of the plant trunk. For moisture content measurement, three seedlings were taken for each variety in three replicates and weighed. A precision scale was used for weight measurements (Figure 4). Then, using the oven drying method, the fresh seedlings were left in the oven to dry for 24 hours at 105 ºC (Figure 4). After this period, samples were taken in the oven to determine their dry weights, their weights were measured again with the same scale and their moisture content was calculated according to the wet basis (% w.b) (ASABE, 2006; Pekitkan et al., 2020; Eliçin et al. 2022).

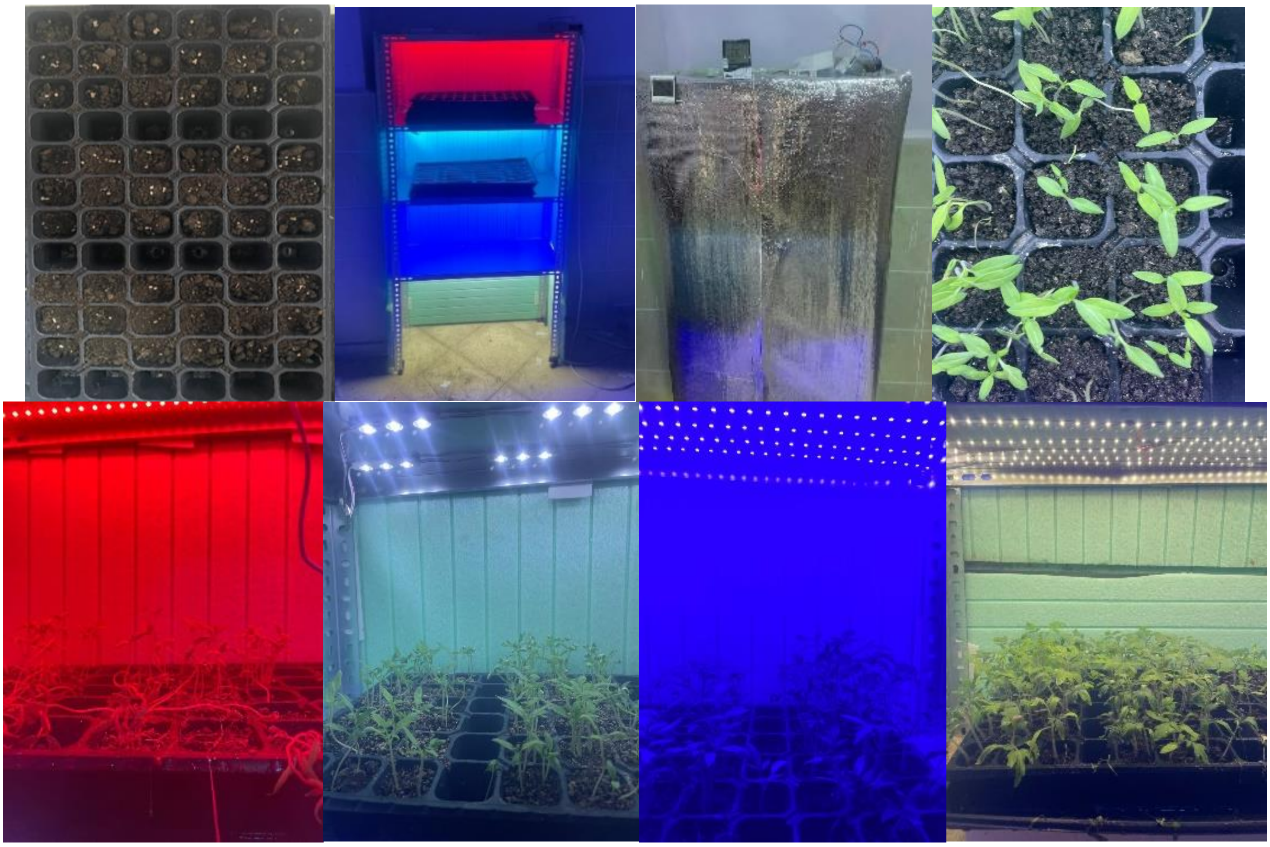

Figure 3. Emerging seeds and their development under different colors.

Figure 4. Weight measurement and drying processes for moisture determination of plants.

Statistical analysis

For statistical comparisons between the data obtained in the experiments, the package program JMP, 13th Version, was used. The experiments were planned according to the randomized parcel trial design and analyzed using the variance analysis method (ANOVA). Comparisons were made according to the DUNCAN test at 5% and 1% significance level.

RESULTS AND DISCUSSION

Plant Height Development

As can be seen in Table 1, the effects of time, variety and light color on the development of plant height were found to be statistically very significant ($p<0.001$). In addition, the difference between the values of measurement time, variety and LED light colors were also found to be very significant ($p<0.001$). In addition to variety, light and measurement time selected as independent parameters, the effects of Time xVariety, Time x Light, Variety x Light, Time x Variety x Light interactions were also statistically very effective on the development of plant height.

Table 1. Results of variance analysis regarding plant height development depending on time, seed type and different light color.

	Seedling Height (cm)				
Variable	**df**	**SS**	**Mean Square**	**F value**	**Probe > F value**
Time	5	1218.32	243,664	14404.16	<,0001*
Error	12	0.20299	0.01692		
Sort	2	467,008	233,504	11101.50	<,0001*
Time xVariety	10	103.59	10,359	492,4965	<,0001*
Error	24	0.50481	0.02103		
Light	3	96,3434	32,1145	4779,994	<,0001*
Time x Light	15	231,613	15,4409	2298,256	<,0001*
Variety x Light	6	7.49532	1.24922	185,9368	<,0001*
Time xVarietyxLight	30	66.1805	2,20602	328,3487	<,0001*
Error	108	0.7256	0.0067		

As can be seen from Figure 5, there was a significant increase in seedling lengths in all varieties and LED light colors depending on time. While the lowest seedling length for all varieties was obtained under the red light, the largest length was obtained under daylight. After the third measurement, it was observed that plant heights increased faster in all varieties and colors. This situation was more pronounced in Karacadağ and Lice varieties. For example, while the plant height was measured as 8 cm in Karacadağ variety on the last measurement (sixth measurement), this value increased by more than 2 times in the same period in daylight and was measured as 17.50 cm. This situation shows that, the effect of light color on the development of plant height is very important. A similar situation was observed in other varieties. The highest seedling length values were obtained in Karacadağ variety, followed by Lice variety. The lowest values were obtained in Ahlat variety (Figure 5). However, the change in plant height increased linearly in time in all varieties and colors. Considering that the development of plant height is an important parameter in terms of earliness and market, it can be stated that these results obtained for early cultivation are important for producers. The use of these colors and varieties will provide significant advantages over other colors and varieties.

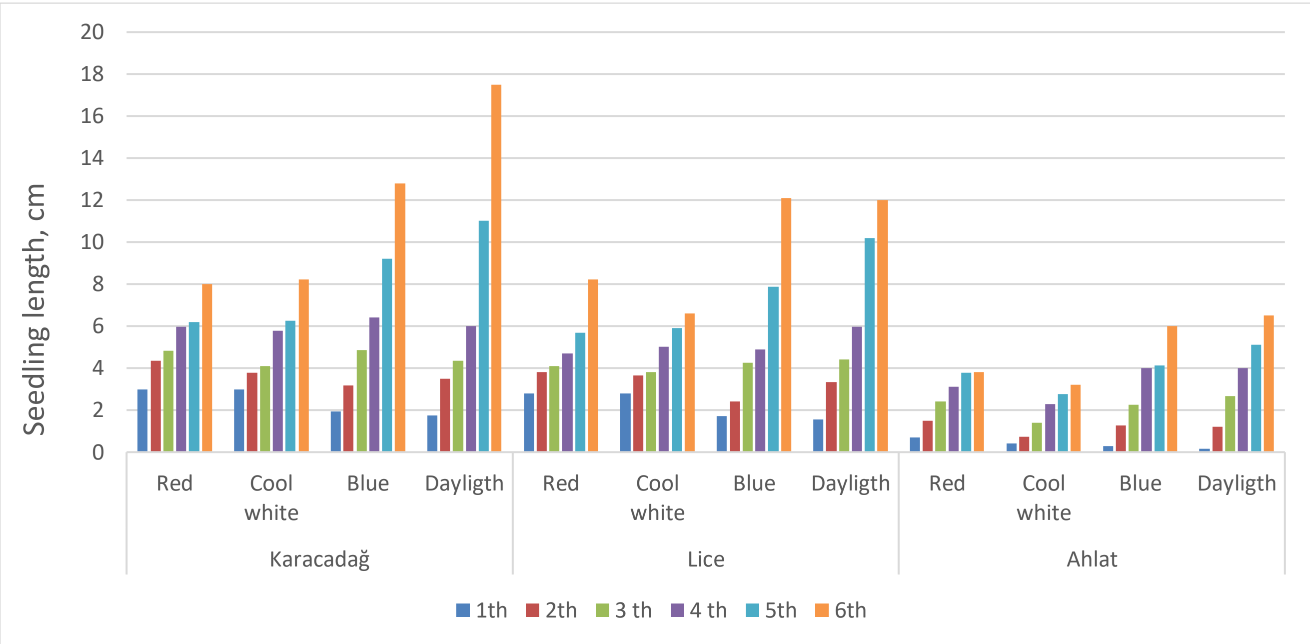

Figure 5. Plant height development depending on time, variety and light color.

Plant Root Length and Stem Diameter

Root lengths and stem diameters were made at the sixth time. Regarding this The measurement results are given in Table 2. As can be seen from the table, the lowest root length was obtained in red light for all varieties, while the best development and length was obtained in daylight. The best and similar values in terms of root length were measured in Karacadağ and Lice varieties. As in height, root length remained low in Ahlat variety. The opposite situation was obtained in height. In daylight, the highest values were obtained in both Karacadağ and Lice varieties.

Table 2. Average root length depending on variety and light color.

Variety	Root Length, cm				Stem Diameter, cm			
	Light Color				Light Color			
	Red	White	Blue	Day	Red	White	Blue	Day
Karacadağ	2.00	3.00	5.20	5.50	0.39	0.41	0.93	1.19
Lice	2.00	2.40	5.90	6.00	0.37	0.35	0.91	1.1
Ahlat	0.25	1.00	2.60	2.20	0.10	0.12	0.43	0.64

Amount of Leaf Chlorophyll

As can be seen from Figure 7, the highest Chl content (SPAD values) in the tomato plants were observed under white light and the low values was obsoerved under red light in all varieties. Although measurements were made at 6 different times during the growing process, SPAD device measurements could not be made in the first 2 measurements due to the small size of the plant leaves. SPAD valuues were made starting from the third measurement time. Therefore, statistical analyses were made starting from the third measurement. A decrease in SPAD values occurred in all varieties as time passed. The difference between them was found to be significant ($p<0.001$). The main reason for this situation can be shown as the increase in leaf width and the decrease in nutrients. However, when the parameters were evaluated as a whole, there was no statistical difference between the third and third time measurements, while there were significant differences between the averages obtained in the measurements made at other times.

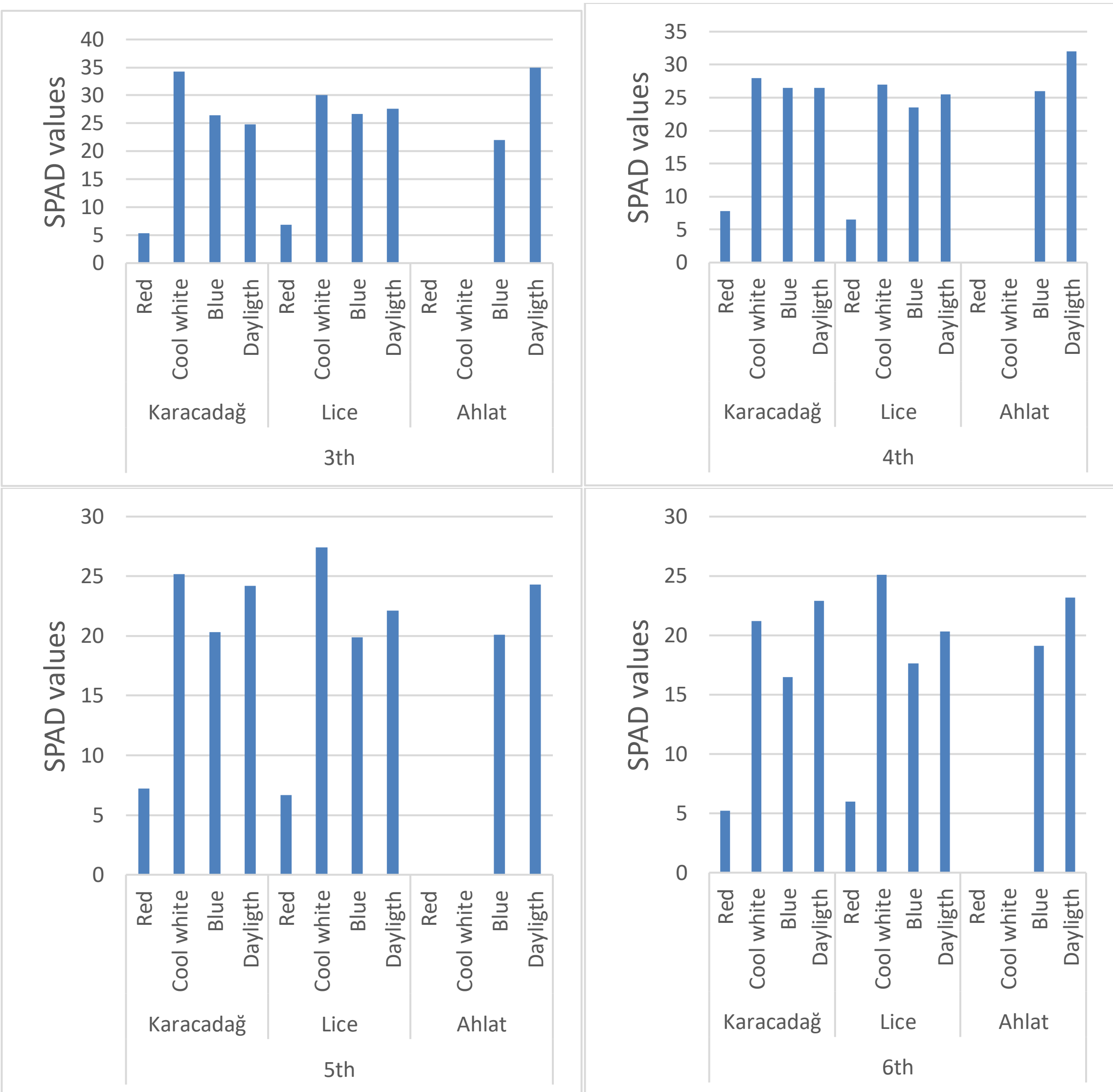

Figure 6. Changes in SPAD values depending on variety, light and time.

Measurements of Light/ Lux

The average lux values (lm/m^2) obtained for the measurements of light amounts are given in Figure 7. As can be seen from the figures, the lowest value in all varieties was obtained in the Karacadağ variety. The main reason for this can be shown as the decrease in lux values as the plant grows taller and gets closer to the light source. In these cases, the light value falling on the environment decreases.

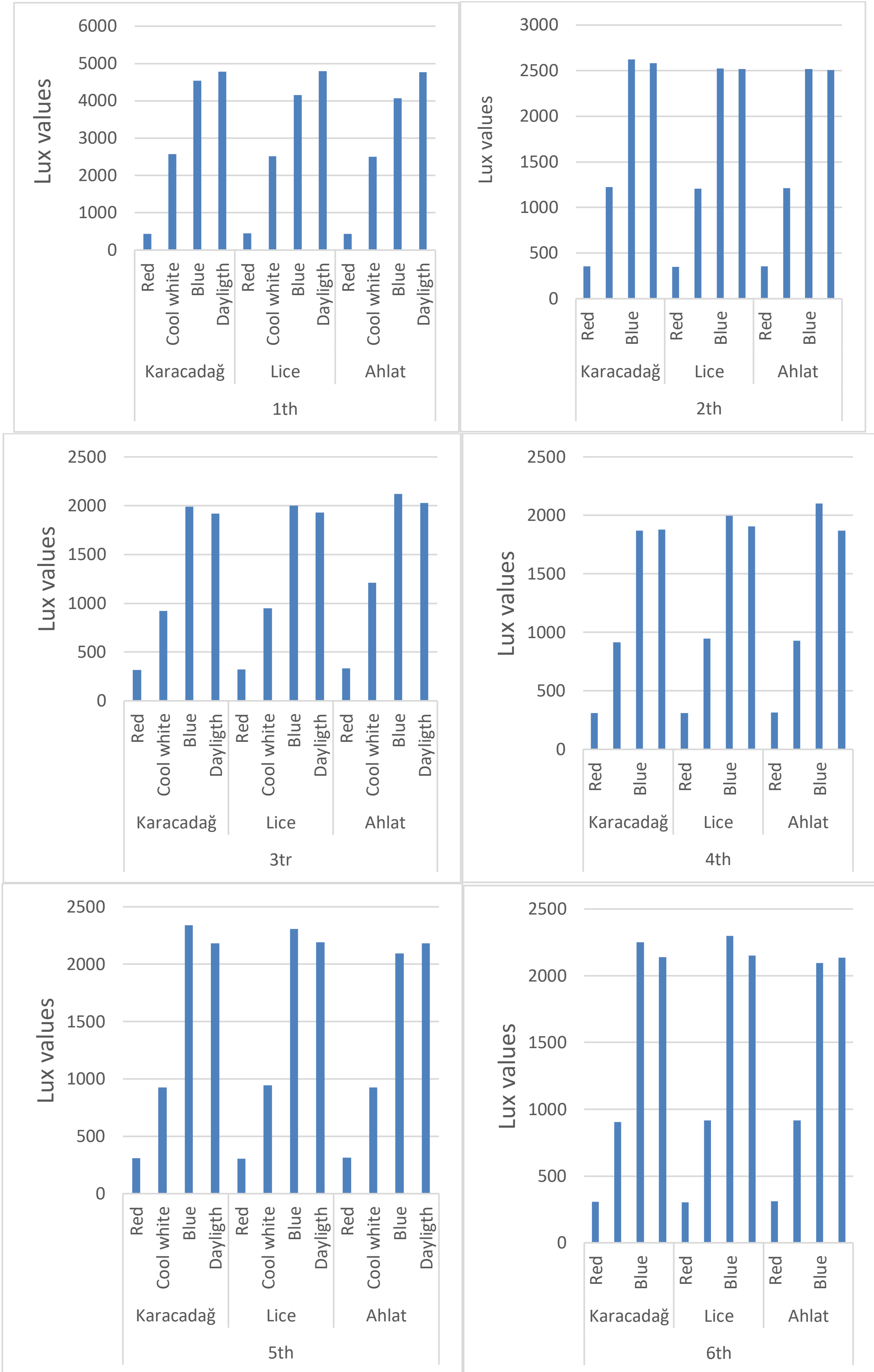

Figure 7. Changes in lux values falling on the plant according to light, time and growth.

Measurements of Leaf Color

L, a and b values were not measured in the first two measurements because the plant leaves were too small. As can be seen from the graphs, measurements were made after the 3rd time period. However, since no numerical difference was observed between the 3-6 measurement values, all measurements were used for the last measurement of the experiment, the 6th measurement values. Similar results were obtained in all varieties and light sources. The L (Whiteness/Blackness) value was measured as 53.8 on average, a: redness (+a) / greenness (-a), -22.35 and b: greenness (+b) / blueness (-b) on average.

Dry and Fresh Weights of Seedlings

At the end of 42 days, the measured values of fresh and dry matter ratios of tomato plants grown under different experimental light applications are given comparatively in Table 3. When the table is examined, it is seen that there is a variability between the seedlings in different colored LED environments and the moisture ratios according to the seedling height, root length and stem diameter.

Table 3. Average fresh and dry matter content of tomato seedlings (%)

Sort	Light	Wet Weight (%)	Dry Weight (g)	Moisture content (%w.b.)	Dry Substance amount (%)
Karacadağ	Red	0.793	0.022	97.22	2.78
	White	1.35	0.0326	98.03	1.97
	Blue	0.993	0.174	80.04	19.96
	Day	1,584	0.410	72.35	27.65
Lice	Red	0.243	0.018	92.33	7.67
	White	1,153	0.034	97.05	2.95
	Blue	1.15	0.145	87.33	12.67
	Day	1,083	0.242	77.66	22.34
Ahlat	Red	0.136	0.011	91.93	8.07
	White	0.31	0.0226	92.69	7.31
	Blue	0.69	0.045	93.48	6.52
	Day	0.436	0.037	91.37	8.63

Average fresh weight of seedlings in 3 tomato varieties with different growing media and light applications was between 0.29 and 1.732 g/seedling, and dry weight values varied between 0.033 and 0.428 g/seedling.

RESULTS

According to the results of this study, the light colors considerably impacts growth development in tomato plants and it is possible to grow plants with LEDs. However, this can vary depending on the plant type, growth stage and light requirements. It has been seen that light quality and quantity are very important for plant growth and that seedlings can be grown healthily under controlled conditions without environmental damage. Results from this study provide new data that may help lighting manufacturers and CEA growers determine essential wavelengths and light colors for tomato growth. After the seed sprouted, it was observed that the initial growth progressed more clearly in the Red LED light compared to other lights. However, it slowed down later and in the daylight, the plant completed its development while the only other color, blue and red, in seedlings grown under LED lights, completion of development was delayed.

Results from this study indicate that, providing new data that may help lighting manufacturers and CEA growers determine essential wavelengths and ligth colors for tomato growth. Also, it will also develop in the future and contribute to increased production and lead to new agricultural areas. Aside from their full color spectrum, LED grow lights are different from regular LED lights due to their extremely high light output. While regular lights focus on lumens, grow lights focus on PAR. A regular LED bulb has a low PAR and can successfully grow plants with low light requirements, as shown in the experiment on tomato plants.

Compliance with Ethical Standards

Peer Review

This article has been reviewed by independent experts in the field using a rigorous double-blind peer review process.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

All authors contributed equally to the study design, data collection, analysis, and manuscript preparation.

Ethics Committee Approval

Ethical approval was not required for this study.

Consent to Participate / Publish

Not applicable.

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