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# Effects Of Dıfferent Wavelenght Led Lıghtıng On Yıeld And Qualıty In Curly Salad Lettuce (*Lactuca sativa var. crispa*) Cultıvatıon

Yusuf Ali Arif [1]
*Hormuud University, Faculty of Agriculture [1]*

***ABSTRACT***
*In this study, the effects of LED lighting with different wavelengths on yield and quality were determined in the cultivation of curly leaf lettuce (Lactuca sativa var. crisp). For this purpose, eight different light applications, namely White (W), red (R), blue (B), Far-red (FR), R+FR, B+FR, R+B, and R+B+FR, 16/8 of photoperiod and 200±20 µmol m-2 s-1 light intensity conditions were used in the research. The efficacy of the applications was tested under controlled conditions in the Sementel curly-leaf salad variety, in a climate room with a lighting system. In the experiment, total plant weight, plant height, plant width, stem diameter, root length, root throat diameter, the total number of leaves, number of discarded leaves, number of marketable leaves, marketable plant weight, leaf dry weight, root fresh weight, root dry weight, Analyzes were made in terms of water-soluble dry matter, pH, titratable acidity, relative chlorophyll amount, color (L*a*b*). There were significant differences in terms of quality parameters in curly leaf lettuce plants grown using different light applications. Among the applications, close values were obtained in the other applications, except for the W, R, and FR applications. In terms of total plant weight, root throat diameter, total leaf number, marketable leaf number, and marketable plant weight the white light application were obtained the highest result. The highest results were obtained in terms of root dry weight, leaf dry weight, and hue from red (R) light application. In FR, all parameters except L*a*b* and plant height gave the lowest results. In terms of pH, similar results were obtained from all applications. As a result, monochromic red and white light are more effective in lettuce. In addition, it can be thought that reducing the amount of blue and far-red light applications can create more positive results.*

***Key Words**: LED lighting, Curly Salad, yield, quality*

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## I. INTRODUCTION

Lettuce is a type of vegetable that is consumed worldwide and is important in terms of nutritional content. The Food and Agriculture Organization of the United Nations reported that global lettuce reached 29 million tons, half of which was produced by China. After China, the United States, Spain, Italy and Japan follow (Anonymous 2020).

Lettuce is a rich source of vitamins K and A and has numerous impressive health benefits. This can help control inflammation, reduce body weight, improve brain health and reduce the risk of cardiovascular disease (Ismail and Mirza, 2015). Lettuce is in high demand among vegetables. The world population is growing rapidly and the number of people living in urban areas is expected to nearly double in 30 years. With the increasing population, the demand for vegetables and products on arable land is also increasing. (Kozai 2016).

Crop production is faced with various obstacles such as the decrease of arable land and the number of farmers. Density on the ecosystem leads to loss of biodiversity and green space. Vegetable growing is affected by climatic conditions and high levels of environmental pollution damaging the soil. In addition, resources such as fresh water, fossil fuels and biomass are expected to be insufficient in the near future (Benke and Tomakin 2017).

With indoor hydroponic system, production can be carried out anywhere and all year round, regardless of climate or soil. In countries where the growing season is limited, this technique is a good option for the year-round production of fresh vegetables and herbs (Kang et al. 2013). One of the benefits of water culture in urban areas is the ability to produce where crops are consumed and the reduced need for transportation. By using a lighting system compatible with vegetable production in water culture, the growth period can be shortened, the yield can be increased by using more than one shelf, continuity in production can be ensured, the density of plants can be increased and waste control can be made (Naoz 2016).

Although sunlight is the cheapest energy source, it is not always sufficient, especially in agricultural production. For this reason, the use of artificial light sources in conditions of insufficient illumination, in artificial production areas and closed rooms is of great importance. The use of artificial lights in greenhouse cultivation, indoor cultivation and tissue culture studies is increasing and is of great importance (Çakırer et al. 2017).

For plants, light is one of the most important environmental factors representing the energy source in photosynthesis. Light is the basic signal that regulates the growth and development processes of the plant throughout its entire life cycle. (Silvestri et al. 2019).

Light quality plays an important role, from seed germination to leaf development and flowering. In summary, light is an extremely important and powerful external signal that affects the plant development process (Zhou et al. 2014).

Light condition (light intensity, light quality and photoperiod) is one of the most important environmental variables in regulating vegetable growth, development and photochemical accumulation, especially for vegetables grown in controlled environments. With the development of light-emitting diode (LED) technology, studies have become more common in order to regulate light environments, to provide ideal light quality, intensity and photoperiod for indoor environments (Bian et al. 2015).

In this study, the effects of light intensity, photoperiod and different light wavelengths and their mixtures on the growth and quality of lettuce grown in Stagnant water culture were investigated to determine the optimum light recipe for the production of commercial lettuce in a controlled environment with artificial light.

## II. MATERIAL AND METHOD

This research was carried out in the Indoor Plant Growth System of the Department of Horticulture, Faculty of Agriculture, Ankara University, in the period of 2020-2021, in July-August.

MATERIAL

Plant Material

In this study, Semental curly leaf lettuce (Lactuca sativa var. Crispa) variety obtained from Başaran Fide Company was used as plant material. The characteristics of the curly salad variety used as vegetable material in the experiment are briefly introduced below. Semental curly salad variety is not only early maturity variety but also a variety with a large head. It has a high level of dark green color and curly structure. It is both a homogeneous variety and resistant to uprooting. It is a very tasty variety with juicy and crunchy leaves. Greenhouse, low tunnel and field are produced (Anonymous, 2020).

The Cultivation Area

The experiment was carried out, long trays shelves with on 8 cm deep, 29 cm wide and 40 cm length in the LED lighting system climate room of the Department of Horticulture, Faculty of Agriculture, Ankara University. A black garbage bag is covered on the outside of the trays. The grown plants were planted in gray colored Styrofoam viols with a distance of 15 cm between plants and 15 cm between two rows. The length of the Styrofoam is 45 cm, its width is 35 cm, and its thickness is 2 cm. In the trays; stagnant water culture system was used. In this system, 5 liters of water was placed in each tray and the seedlings were planted by closing gray Styrofoam with six holes and a distance of 15 cm between both holes.

Nutrient Solution and Oxygen Supply

Nutrient solution was prepared before transplanting seedlings in the experiment. In fertilization, 5 L of solution was prepared for each application and 5 L of nutrient solution per tray was given to the water used as the growing medium, since it contained nutrient solution. The irrigation interval is arranged to be twice a week. To prepare a 1.2 EC nutrient solution, 7 g of fertilizer was put into 5 L of water. To prepare the nutrient solution, 20:20:20 NPK+ME fertilizer (Nitrogen, Phosphorus, Potassium) was used. The pH of the solution was prepared to be 6-6.8. Oxygen was given to the plants by keeping them in the water in each tray/dish for one minute using an aquarium pump twice at two irrigation intervals. The temperature and humidity values of the growing room were recorded throughout the experiment using the Log Tag Brand Temperature and Humidity Recorder (datalogger).

LED Lighting System

In the experiment, LED modules consisting of white, red, blue and far-red light wavelengths and their combinations were used. The photoperiod applied was 16/8 hours light/dark (Zhang et al. 2018). The light intensity was adjusted to be approximately 200 ± 20 µmol m-2 s-1 for each application (Naznin et al. 2019).

Light Applications

1. White LED (W)
2. Red LED (R)
3. Blue LED (B)
4. Far-red LED (FR)

5. Red+Blue LED (R+B)
6. Red+far-red LED (K+FR)
7. Blue+Far-red LED (M+FR)
8. Red+Blue+Farred LED (R+B+FR)

METHOD

Methods and Procedures of the Research

Stagnant water culture system was used in the study. In the experiment, a randomized block design with 3 replications was applied. 8 plants were used in each replication and 24 plants were used in each treatment. A total of 192 plants were grown in 8 treatments. Semental curly leaf salad variety was planted on July 28, 2020, in double rows at 15 cm intervals.

Temperature and Humidity Measurements

During the experiment, a total of 4029 readings were made at 15-minute intervals with the help of Log Tag Brand Temperature and Humidity Recorder (datalogger). The first reading was made on 07.30.2020 at 16:51:57 and the last reading was recorded on 09.10.2020 at 15:51:57. In the experiment, the relative humidity and temperature average reading values were 21.8°C and 71.3%, respectively. The highest temperature was 29.7°C on 07.30.2020 at 16:51:57, and the lowest was 19.2°C on 08.01.2020 at 14:06:57. The highest humidity value was recorded as 85.9% on 08.27.2020 at 14:51:57, and the lowest humidity value was recorded as 40.2% on 09.10.2020 at 15:51:57.

Research Design and Statistical Analyzes

In the experiment, the data obtained in terms of the effects of different LED lighting applications were evaluated at the experiment level of random plots in the factorial order. The experiment has eight treatment levels, namely W, R, B, FR, R+FR, B+FR, R+B and R+B+FR. Experiment results were checked using the Minitab package program (MINITAB 17) with the analysis of variance method. The significant differences that emerged were determined by the Tukey test.

## III. RESULTS AND DISCUSSION

Time to Harvest and Earliness

The seedlings of the Semental variety were transplanted on 28.07.2020. By observing plant growth and development, the plants that came to the harvest stage were harvested on 02.09.2020, 36 days after the transplanting date, and evaluated together with all applications. The Semental seedlings grown under W, R, B, FR, R+FR, B+FR, R+B and R+B+FR applications are evaluated in terms of earliness; As can be seen in Figure 4.1, it was observed that plants in R+FR, R and W light treatments showed better growth than plants in other treatments, respectively.


Figure 4.1: Differences of plants in terms of earliness according to applications

**Plant Height (cm), Plant Width (cm), Root Diameter (mm), Total Plant Weight (g)**

As a result of the analysis, statistical differences were found in terms of plant height (cm), plant width (cm), stem diameter (mm), total plant weight (g) according to the applications. The results of the applications are given in Table 4.1. Also, plants grown under B, K+FR, M, K, K+M+FR, M+FR, K+M, will be seen in Figure 4.6.

**Table 4.1 Differences of Plant Height (cm), Plant Width (cm), Stem Diameter (mm), Total Plant Weight (g) values according to the averages**

| Treatment | Plant Height (cm) | Plant Width (cm) | Stem Diameter (mm) | Total Plant Weight (g) |
|---|---|---|---|---|
| **W** | 19.80±0.69 BC | 23.33±1.45 A | 13.17±0.58 AB | 126.47±13.85A |
| **R+FR** | 40.67±0.88 A | 21.28±0.35 A | 10.05±0.88 B | 89.76±3.24 B |
| **B** | 18.61±0.42 BCD | 20.67±0.88 A | 11.71±0.51 AB | 86.18±4.14B |
| **R** | 17.50±0.17 DEF | 20.22±0.51 A | 11.22±1.11 AB | 119.10±11.27A |
| **R+B+FR** | 16.39±0.82 EF | 17.05±0.95 B | 13.91±0.97 AB | 96.69±2.40 B |
| **B+FR** | 18.00±1.33 CDE | 17.00±0.58 B | 10.99±0.28 AB | 58.13±0.66 C |
| **R+M** | 15.67±0.34 F | 15.78±1.83BC | 15.30±4.83 A | 89.10±3.55 B |
| **FR** | 20.28±0.35 B | 13.28±1.42 C | 3.17±0.26 C | 6.097±0.18 D |

**The differences between the means shown with different letters are significant at the $p \leq 0.05$ level.**

As can be seen in Table 4.1 and Figure 4.2, it was determined that the highest plant height was in the plants grown under R+FR application (40.67 cm), and the lowest plant height was (15.67 cm) in the plants grown under R+B treatment. In terms of plant width, the highest plant width among the applications is obtained from W light application (23.33 cm), followed by R, R+B+FR applications. The lowest plant width is observed in plants (13.28 cm) in which FR light is applied.

According to the stem diameter, the plants grown under the R+B application had the highest plant stem diameter (15.30 mm) among the treatments. The lowest plant stem diameter was obtained from the FR application (3.17 mm). In terms of total plant weight, the highest total plant weight value among the treatments was observed in plants grown in W light treatment (126.47 g). The lowest value was observed in plants grown under FR application (6.10 g).

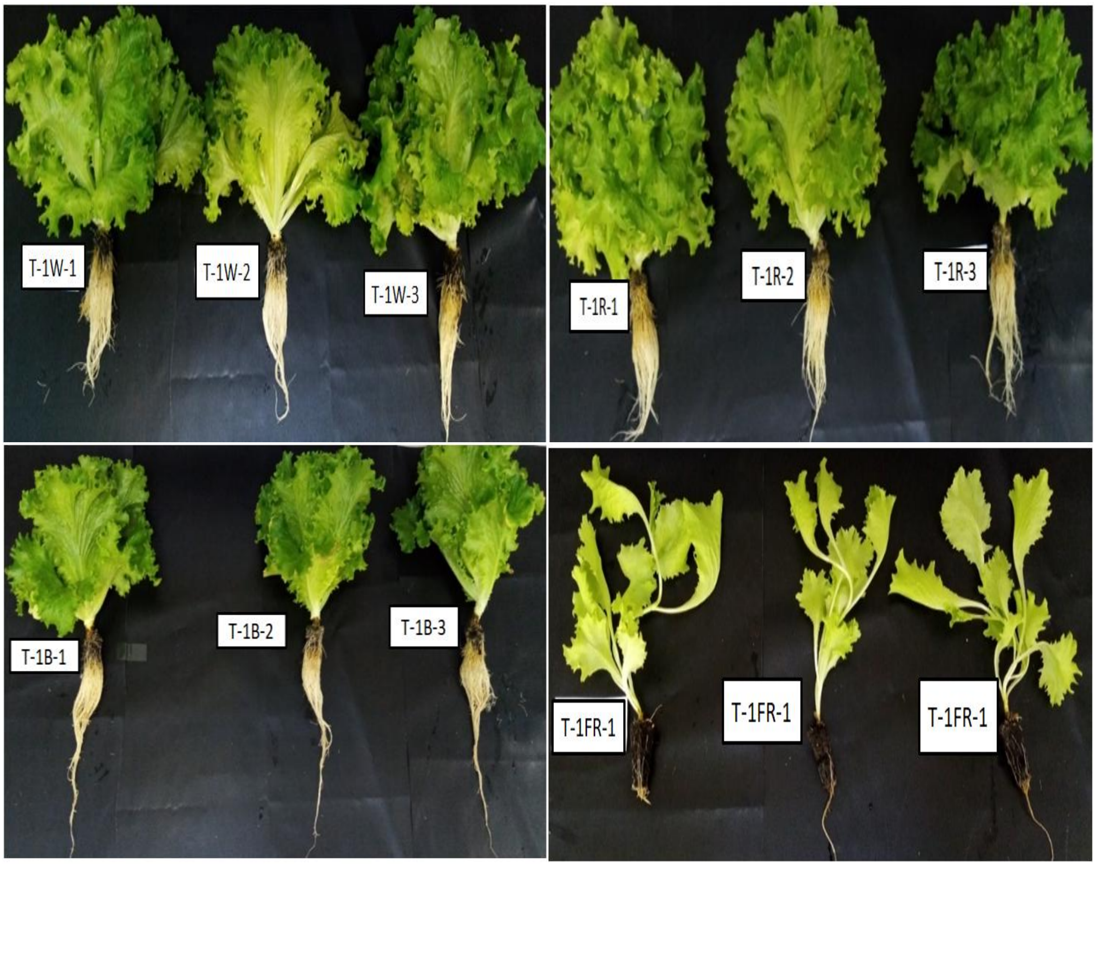


Figure 4.6 Plants grown under W, R+FR, B, R, R+B+FR, B+FR, R+B, FR

**4.3 Root Length (cm), Root Fresh Weight (g), Root Throat Diameter (mm), Root Dry Weight (g)**

As a result of the analysis, there were statistical differences in terms of root length (cm), root fresh weight (g), root throat diameter (mm), root dry weight (g) according to the applications. The results of the applications are given in Table 4.2. In addition, the root lengths of the plants grown under W, R+FR, B, R, R+B+FR, B+FR, R+B, FR can be seen in Figure 4.11.

**Table 4.2 Differences of Root Length (cm), Root Fresh Weight (g), Root Throat Diameter (mm), Root Dry Weight (g) values according to the averages**

| Treatments | Root Length (cm) | Root Fresh Weight (g) | Root Throat Diameter(mm) | Root Dry Weight (g) |
|---|---|---|---|---|
| **R+FR** | 25.94±2.08 A | 4.69±0.70 B | 0.90±0.15 C | 0.46±0.07 BC |
| **B+FR** | 24.89±4.22 AB | 4.58±0.33 B | 0.97±0.07 BC | 0.40±0.02 C |
| **R+B** | 22.63±0.52 ABC | 6.41±0.41 A | 0.97±0.06 BC | 0.48±0.06 BC |
| **B** | 22.17±2.18 ABC | 4.73±0.74 B | 1.18±0.07 AB | 0.45±0.04 BC |
| **R+B+FR** | 20.72±0.54 ABC | 6.22±0.08 A | 0.98±0.10 BC | 0.56±0.02 B |
| **W** | 19.00±2.75 BC | 5.35±0.44 AB | 1.28±0.04 A | 0.55±0.04 B |
| **R** | 17.22±1.30 CD | 5.77±0.61 AB | 0.97±0.12 BC | 0.76±0.07 A |
| **FR** | 11.67±0.93 D | 0.11±0.0 4C | 0.32±0.02 D | 0.02±0.01 D |

**The differences between the means indicated by different letters are significant at the $p \leq 0.05$ level.**

As can be seen in Table 4.2 and Figure 4.7, the highest root length among the treatments was observed in the plants grown in the R+FR application (25.94 cm), while the lowest root length was observed in the plants grown in the FR application (11.67 cm). In terms of root fresh weight, as shown in Table 4.2 and Figure 4.8, the plants grown in R+B (6.41g) and R+B+FR (6.22g) applications had the highest values. No statistical difference was observed between them. The lowest root fresh weight was observed in plants grown under FR (0.11 g).

In terms of root throat diameter, as shown in Table 4.2 and Figure 4.9, the highest root throat diameter value was obtained from plants (1.28 mm) grown in W light treatment. The lowest root collar diameter value was obtained from the plants grown in the FR application (0.32 mm). In terms of root dry weight, the highest root dry weight was observed in plants grown in R light application (0.76 g) among the treatments as shown in Table 4.2 and Figure 4.10. The lowest root dry weight was obtained from the plants grown in the FR application (0.02 g).

**4.4 Total Number of Leaves (Number), Number of Discarded Leaves (Number), Number of Marketable Leaves (Number), Marketable Plant Weight (g) and Dry Leaf Weight (g)**

The differences between applications in terms of total number of leaves (pieces/plant), number of discarded leaves (number/plant), number of marketable leaves (number/plant), marketable plant weight (g) and dry leaf weight (g) are given in Table 4.2.

Table 4.3 Differences in Total Number of Leaves (Number), Number of Discarded Leaves (Number), Number of Marketable Leaves (Number), Marketable Plant Weight (g) and Dry Leaf Weight (g) according to applications

| **Treatments** | **Total Number of Leaves (pieces/plant)** | **Number of Discarded Leaves (pieces/plant)** | **Number of Marketable Leaves (pieces/plant)** | **Marketable Plant Weight (g)** | **Dry Leaf Weight (g)** |
|---|---|---|---|---|---|
| **R+FR** | 22.67±1.53 DE | 7.12±0.96 A | 15.67±0.67 C | 83.79±5.78 B | 4.33±0.29 BC |
| **B+FR** | 19.00±0.330 E | 6.56±0.77 AB | 12.44±0.51 D | 50.54±0.37 C | 2.75±0.05 D |
| **R+B** | 29.67±2.91 B | 7.11±2.11 A | 22.67±2.19 B | 79.70±3.90 B | 3.96±0.13 C |
| **B** | 23.78±1.65 CD | 7.56±0.96 A | 16.33±0.88 C | 78.45±4.27 B | 4.051±0.30 C |
| **R+B+FR** | 27.33±0.88 BC | 5.22±1.39 AB | 22.11±1.58B | 87.49±2.47 B | 4.33±0.23 BC |
| **W** | 34.33±1.21 A | 8.22±0.51 A | 26.33±0.67 A | 120.32±13.98 A | 5.18±0.85 AB |
| **R** | 31.33±1.20 AB | 7.44±0.51 A | 23.89±0.77 AB | 110.67±10.74 A | 5.74±0.55 A |
| **FR** | 12.33±0.58 F | 3.67±0.34 B | 8.89±0.19E | 4.97±0.14 D | 0.19±0.02 E |

**The p≤0.05 level of differences between the applications indicated with different letters is significant.**

As it will be shown in Table 4.2 and Figure 4.12, the plants grown under W light application had the highest total leaf number (numbers) (34.33 units), while the lowest total leaf number was obtained from the application of FR (12.33 units). In terms of the number of discarded leaves, the highest value among the applications was seen in the W light application (8.22 pieces/plant). This is followed by B (7.56 units/plant), R (7.44 units/plant) and R+FR (7.12 units/plant) applications, and no statistical difference was observed between them. The lowest number of discarded leaves was obtained from plants grown under FR application (3.67 pieces/plant).

In terms of the number of marketable leaves, as can be seen in Table 4.2 and Figure 4.14; There were statistical differences between applications. The highest number of marketable leaves was obtained from plants grown in W light treatment (22.11 units), and the lowest number of marketable leaves was obtained from FR application (8.89 units). As shown in Table 4.2 and Figure 4.15, the plants grown under light application (120.32 g) have the highest/highest marketable plant weight among treatments, followed by R light application (110.67 g). The lowest value was obtained from the FR Application (4.97g).

In terms of leaf dry weight, statistical differences were observed between treatments. The plants grown in the R light treatment had the highest value (5.74g). The lowest marketable plant weight value was obtained from the plants grown in the FR treatment (0.19 g).

**4.5 Leaf Color: The results of the treatments in terms of L*, a*, b*, chroma and hue are shown in table 4.3.**

| **Treatments** | ***L**** | ***a**** | ***b**** | **Chroma** | **Hue°** |
|---|---|---|---|---|---|
| **FR** | 58.10±1.10 A | -17.57±0.47 A | 32.82±1.07 ABC | 37.22±1.16 ABC | 118.17±0.35 E |
| **R** | 51.78±1.43 B | -20.78±1.31 B | 37.10±2.92 A | 42.53±3.18 A | 119.28±0.51 DE |
| **R+FR** | 49.77±1.57 BC | -20.65±0.76 B | 35.14±1.87 AB | 40.76±1.99 AB | 120.46±0.46CD E |
| **R+B+FR** | 48.06±0.10 BCD | -21.86±0.51 B | 35.33±0.35 AB | 41.55±0.60 AB | 121.747±0.48B CD |
| **M+FR** | 47.26±1.72 BCD | -20.65±0.51 B | 31.79±1.45 ABC | 37.92±0.95 ABC | 123.03±1.82 ABC |
| **W** | 45.67±2.46 CD | -21.09±1.14 B | 30.53±2.89 BC | 37.44±2.90 ABC | 124.69±1.25 B |
| **B** | 45.01±0.23 CD | -19.80±0.51 AB | 27.16±0.58 C | 33.61±0.82 C | 126.09±0.25 A |
| **R+B** | 42.55±4.43 D | -19.50±1.04 AB | 29.57±4.07 BC | 35.44±3.97 BC | 123.57±2.18 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | ABC |

**The p≤0.05 level of differences between the applications indicated with different letters is significant.**

As it will be shown in Table 4.3 and Figure 4.17, the highest/highest L* value among the treatments was seen in the plants grown in the FR treatment (58.10), followed by the R light application (51.78). The lowest L value was obtained from the plants grown in the R+B treatments (42.55). In terms of a* value, the highest/highest a* value among the treatments was observed in plants grown in FR application (-17.57), followed by R (-20.78), R+FR (-20.65), R+B+FR, respectively. (-21.86), B+FR (-20.65) and W (-21.16) treatments were followed and there was no statistical difference between them.

In terms of b* value, the highest b*value among the treatments was obtained in plants with R light application (37.10), followed by R+B+FR (35.33) and R+FR (35.14) applications, respectively. Plants grown under B light application had the lowest a value (27.16). According to the chroma value, the highest/highest chroma value was obtained in plants grown in R light application (42.53), followed by R+B+FR (41.55) and R+FR (40.76) applications, respectively. The lowest chroma value was obtained from the B light application (42.53). And in terms of hue value, the highest hue value among the treatments was observed in plants grown in B light application (126.09), followed by W light application (124.69). The lowest hue value was obtained from the FR application (118.17).

**Water Soluble Dry Matter (WSDM) (%), pH, Titratable Acidity (TA) (%) and Relative Chlorophyll**

Statistically different results were obtained between the applications in terms of WSDM, pH, Titratable Acidity, and these results are given in Table 4.4 and Figure 4.22.

Table 4.5. Variation of Water-Soluble Dry Matter (WSDM) (%), pH, Titratable Acidity (TA) (%) and Relative Chlorophyll according to applications

| Treatments | WSDM (%) | PH | TA (%) | Titratable Acidity (TA) (%) |
|---|---|---|---|---|
| **R+FR** | 8.00±0.27 A | 6.27±0.06 A | 0.11±0.02 BCD | 143.53±7.72 D |
| **R** | 7.23±0.50 B | 6.27±0.06 A | 0.08±0.01 D | 184.90±21.40 C |
| **B+FR** | 6.53±0.12 BC | 6.17±0.06 A | 0.12±0.01 BC | 228.00±18.90 AB |
| **R+B+FR** | 6.47±0.21 C | 6.23±0.06 A | 0.08±0.01 D | 240.33±11.37AB |
| **B** | 6.30±0.00 C | 6.10±0.00 A | 0.15±0.01 A | 261.67±12.87A |
| **R+B** | 6.27±0.25 C | 6.23±0.06 A | 0.10±0.01 BCD | 261.60±5.38 A |
| **W** | 5.93±0.32 C | 6.10±0.10 A | 0.12±0.01 B | 212.80±21.30 BC |
| **FR** | 4.73±0.12 D | 6.13±0.06 A | 0.09±0.00 CD | 81.00±3.90 E |

The p≤0.05 level of differences between applications with different letters is significant.

As it will be shown in Table 4.4 and Figure 4.22, the plants grown in R+FR application (8.00%) had the highest/Excess amount of WSDM among the treatments, followed by R light application (7.23%). The lowest amount of WSDM was obtained from the plants grown in the FR application (4.73%).In terms of pH value the highest pH values were obtained from plants grown in R+FR (6.27) and R (6.27) applications, while the lowest pH values were obtained from W (6.10) and B (6.10) applications. In general, no statistical difference was observed between the applications.

In terms of TA, the highest TA value among the treatments was obtained in plants grown in B light application (0.15%), followed by W light application (0.12%). The lowest pH values were obtained from plants grown in R (0.8%) and R+B+FR (0.8%) applications. In terms of relative chlorophyll, the highest relative amount of chlorophyll was observed in plants grown in B (261.67) and R+B (261.60) applications, while the lowest relative amount of chlorophyll was obtained from plants grown in FR application (81.00).

## IV. DISCUSSION

Curly Salad is a type of vegetable commonly grown in Turkey. Its production is important both economically and commercially. Curly lettuce is an important type of vegetable grown in greenhouse cultivation and most commonly in aquaculture around the world. This type of vegetable is seen as a model plant in scientific studies due to its sensitivity to different light qualities for rapid growth and development (Dougher and Bagbee 2001).

Light spectral quality is the relative intensity and amount of different wavelengths emitted by a light source and detected by photoreceptors within a plant. In order to increase the yield and quality of the curly lettuce plant, it is necessary to know the interaction of the environment in which the plant is grown with various environmental factors. This study was established at Ankara University, Faculty of Agriculture, Department of Horticulture, curly lettuce was grown in stagnant water culture, and the effects of different spectra on plant growth, development and quality characteristics were investigated by using LED lighting with different wavelengths. Two different LED lighting groups were used in the study. The first group is monochrome; white, red, blue, far-red; the second group is those with more than one color combination; red + far-red, blue + far-red,

red + blue, red + blue + far-red. There were statistically significant differences between the applications in terms of the results obtained in the study.

According to the results of the application, the plants grown under white (W) light had the highest total plant weight, root collar diameter, total number of leaves, number of marketable leaves, and marketable plant weight compared to other treatments. In terms of root dry weight, leaf dry weight and hue value, the highest results were obtained in plants treated with red (R) light. In terms of titratable acidity and relative chlorophyll amount, the results in blue (B) light application were higher than all other applications. In terms of the number of discarded leaves, the same results were obtained in other applications, except for B+FR and R+B+FR applications. In terms of pH, similar results were obtained in all applications.

In terms of relative chlorophyll, the highest results were obtained in B and B+FR applications, but terms of plant width, higher results were obtained in W, R, B and B+FR applications compared to other applications. The highest plant heights were obtained from R+FR and FR applications, respectively. In terms of L*, a*, FR gave the highest result compared to other applications. The lowest plant weight, root throat diameter, total leaf number, marketable leaf number, marketable plant weight, root dry weight, and leaf dry weight were obtained when compared to other applications. When the research results are evaluated as a whole, monochrome white LED lighting generally increased the biomass production of lettuce when used as a light source in lettuce cultivation. This is because white light can penetrate plant leaves better for photosynthesis than red and blue LED light.

Similarly, Ohashi-Kaneko et al. (2007), it was determined that the leaf area and the number of leaves increased in lettuce treated with monochromatic white light. In another study on this subject, it was observed that low light intensity white light increased the plant fresh weight, plant height and number of leaves in lettuce (Matysiak and Koalski 2019). The full spectrum exists in white light and in colored rays of other wavelengths.

In curly salads grown only under red light, the leaves are curved and take a curled shape. Lettuce grown in red light showed good biomass production and root development, resulting in decreased green color intensity, and has poor quality of marketable leaves. These results are also supported by the scientific research results of different researchers. As the red light used alone is not sufficient to maximize photosynthesis mechanism of the leaf, the photosynthesis of the plant is negatively affected (Trouborst et al. 2016).

Red wavelength light strengthens the starch content by inhibiting the transport of photosynthesis from the leaves, which can negatively affect the production of a number of flowers and fruits in plants (Saebo et al. 1995). Lettuce grown under red light grows slowly and produces less stiff leaves (Hoenecke et al. 1992).

The highest result was obtained in terms of titratable acidity and relative chlorophyll amount in blue light compared to all other applications. In other examined parameters, lower results were obtained compared to the K, B, K+FR and K+M+FR applications. In this study, the yield and quality of plants that were treated with blue light alone were adversely affected. On the other hand, constant illumination with single blue light or high amounts of white light can lead to adverse effects such as decreased net photosynthetic rate in many species due to chloroplast avoidance responses and impaired mesophyll conductivity (Loreto et al. 2009). Additionally, the blue light also inhibits leaf expansion. The expansion of the horizontal and vertical directions of the leaf is controlled by different genes (Tsukaya 1998). Blue light modulates cryptochromes to suppress stem elongation, leaf expansion and shoot weight in general, along with regulating chlorophyll and anthocyanin content (Wollaeger and Runkle 2015). The plants grown in the FR application gave the highest results in terms of L*, a* color parameters compared to other applications. No growth or development was observed in leaves, stems and roots in FR applied curly leaf salads. This is due to the fact that plants' responses to FR light are generally similar to their responses to shade, as explained by Franklin (2008). The far-red also has a negative effect on capillary root density, which reduces or completely limits the absorption of nutrients dissolved in water. In terms of relative chlorophyll, the highest results were obtained in B and B+FR applications. According to Pedale et al. (2016), the antagonistic effects of FR+B radiation on growth and development responses may be linked to the convergent control of functionally similar genes by both phytochromes and cryptochromes.

On the other hand, the plants grown in R+FR light were the highest plant height compared to the other applications. In addition to this, R+FR decrease the number of leaves in the plant, leaf color, leaf chlorophyll content, and increase the internode length and the number of discarded leaves in the plant. As reported by Reddy and Finlayson (2014), red and far-red light regulate the auxin frequency to prevent branching, increasing the level of auxin acting downstream of Phytochrome B, causing the shoot to take longer and the growth of lateral buds to decrease.

Plants grown under R+B+FR light combination were positively affected in all parameters compared to other treatments because the interactions between FR radiation and B:R depend on the B photon flux density. B radiation modulates cryptochromes to suppress stem elongation, leaf expansion, and plant fresh weight in general, but favors chlorophyll and anthocyanin concentration (Son and Oh 2013). For this reason, blue light should always be proportionally much less than red light and more than far-red light suggests a good result.

Considering the research results and previous studies; it has been concluded that red and blue light applications alone are suitable to increase yield and quality in the production of curly leaf lettuce, but better results will be obtained by adding a small amount of blue light with red light. It has been deduced that infrared and blue light applications alone affect yield and quality negatively in the production of curly leaf lettuce and it is not very suitable to use it as a light source alone. In red+far-red and red+blue+far-red applications, if the amount of far-red and blue light reduced in both applications, it is predicted that higher quality and yield can be obtained for the production of curly leaf salad.

## V. CONCLUSION

Finally, it has been concluded that reducing the amount of blue and far-red light in all applications will have positive effects in order to increase yield and quality in the production of curly leaf salad indoor systems. It has been seen that the combinations different wavelengths in plants can have significant effects on the growth of plants, affect yield and quality.

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