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# Effects of different LED light spectra on growth and quality parameters of Tulip (*Tulipa spp.*)

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**Abstract**

Tulips (*Liliaceae*) are ornamental plants found growing all around the world. Although tulips are short-day flowers, they are known to positively respond to light treatments. Light plays an important role in plant growth and development of tulips. Accordingly, in this study, we investigated the effects of different light spectra on growth and quality parameters of two tulip cultivated varieties: *Tulipa sp.* 'Ronaldo' and 'Apeldoorn'. Three different LED wavelengths were used: 100% yellow (3000 K), 100% blue (455±5 nm) and 100% red (650±5 nm) in these trials. The LEDs were turned on for 2, 4 or 6 hours a day with a 0 hours dark control. 'Apeldoorn' tulips bloomed earlier than 'Ronaldo' tulips. The results in terms of greater plant height, bud length, flower diameter, flower length, flower stalk thickness, number of leaves and fresh leaf weight were observed in 'Apeldoorn' tulips. This outcome can be attributed to the characteristics of 'Apeldoorn' tulips. Furthermore, in the variety-treatment interaction, the greater results for flower stalk thickness were observed 'Apeldoorn' grown under red and blue LED light, while the greater results for petal number were observed in varieties grown under blue LED light. The greater results for petal fresh weight, petal dry weight, bulb fresh weight, and bulb dry weight were observed in 'Ronaldo' tulips. No statistically significant differences were found for bud diameter and leaf dry weight.

**Keywords:** Blue, Bulb, Flowers, Ornamental, Red, Wavelengths

## INTRODUCTION

Light is an important environmental factor for plant growth and development. Available evidence suggests that a plant's stem elongation, flowering, and quality are affected by light quality, light intensity, and photoperiod (Shao et al., 2020). LEDs have recently become more widely used as a light source for growing plants in greenhouses. LEDs provide light at various wavelengths and have varying effects on plants in terms of plant development, physiology, and morphology (McNellis and Deng, 1995; Kodal et.al., 2025).

Previous research demonstrated that red light is effective in increasing the dry weight of velvet flower seedlings, flower stalk length, and flowering time of cyclamen, as well as the height of ageratum and African marigold seedlings (Heo et al., 2003, 2009; Johkan et al., 2010). Furthermore, other studies documented that blue light can control phototropism, stomatal closure, leaf expansion, and photoprotection, increase the leaf area and dry weight of lettuce, and inhibit ethylene biosynthesis (Heo et al., 2009; Gruszecki et al., 2010). In its turn, green light was found to was found to promote leaf growth and stem elongation and result in a lower chlorophyll a/b ratio (Van et al., 1977). Finally, white light was fount to inhibit flowering and promote the growth of leaves and stems in chrysanthemums (Jeong et al., 2012). *Curcuma* is classified as a facultative long-day plant, typically growing and flowering from July to August (Sour et al., 2025). However, between November and December it becomes dormant in response to shorter days and cooler night temperatures (Hongpakdee et al., 2010). Off-season flowering was achieved using night break lighting techniques (Hagiladi et al., 1996; Criley, 2011; Seelatlao et al., 2023), enabling year-round production in both field and potted systems (Ruamrungsri, 2015). These findings demonstrate that spectral composition is an important regulatory factor in ornamental plant production.

Tulips (*Liliaceae*) grow naturally in the mountainous regions of Anatolia, the Caucasus, the Himalayas at altitudes up to 4000 m, as well as in regions with a dry and hot climate in summer and a cold and humid climate in winter. Tulip plant height varies from 15 to 60 cm, stem length from 5 to 50 cm and bulb diameter from 2.5 to 4 cm. Tulips are attractive flowers with six petals on the flower stem. The planting time of tulips in Türkiye is October-January and the flowering period is February 15-May 15 (Gezgin, 2007).

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In horticulture, tulip bulbs are generally lifted in summer and then stored at room temperature. To ensure early flowering in tulips ( i.e., before Valentine's Day), bulbs should are stored at 17°C for 1-5 weeks before rooting (De Hertogh and Le Nard 1993). Tulip bulbs need a period of low temperature to break dormancy and initiate a floral stalk elongation and flowering after a complete flower formed in the center (Xu and Niimi, 2008). Bulb stored dry for 12 weeks at 5°C (pre-cooled) or 17°C (uncooled) were reported to produce flower stalk elongation and flowering only at 5°C (Lambrecths et al. 1994). These findings demonstrate that low-temperature treatment is necessary to trigger flowering in tulips. However, the interaction between temperature pretreatment and the light spectral composition during subsequent growth remains poorly understood.

Microsporogenesis of anthers occurs during the process of dormancy breaking of tulip bulbs. The microspore mother cells developed sequentially into tetrad microspores, microspores, vacuolated pollens, engorging pollens and mature pollens in bulbs cooled at 4°C. Harvestable flowers with fully developed anthers and viable mature pollen grains were attained in these cooled bulbs. Indole-3-acetic acid was immunolocalized in the anther pollen sacs of bulbs stored at 4°C, but not in those stored at 20°C; this indicates that indole-3-acetic acid is biosynthesized in bulbs during cold storage (Xu and Niimi, 2008). Based on this evidence, the present study aims to investigate the effects of different LED wavelengths on tuber sprouting rate and plant development of different types of tulip tubers in cold storage (5°C).

## MATERIALS AND METHODS

### Materials

The study was conducted at the Cold Storage Research and Application Unit and Under Cover Research and Application Unit of Bursa Uludağ University Faculty of Agriculture, Department of Horticulture. Specifically, two different tulip varieties were used: 'Ronaldo' and 'Apeldoorn' (see Figures 1 and 2). The tulip bulbs had a diameter of 10-12 cm and were purchased from ASYA LALE in Konya. 'Ronaldo' is a triumph type, typically blooms in mid-spring and features dark purple, near-black purple, or dark burgundy shades flowers reaching a height of 45–50 cm. 'Ronaldo' produces single flowers. 'Apeldoorn' is a Darwin hybrid type, blooms in the early-mid season and features red flowers reaching a height of 45–50 cm. It produces single flowers (Malta, 2016).

**Figure1.** 'Ronaldo'

**Figure 2**. 'Apeldoorn'

### Methods

The two types of tulip bulbs were obtained in November and soaked in fungicide (0.5ml/10 L water) (Poyraz and Yaşar, 2005) for 1 h before the bulbs were placed in cold storage (5°C). The bulbs were placed in vials with the shoot tips facing the LED lamps. Three different LED wavelengths were used: yellow 100% (3000 K), blue 100% (455±5 nm), and red 100% (650±5 nm). The control group was placed in the dark.The LEDs in the three groups were turned on for, 2, 4 or 6 h/day (see Figures 4-6). The distance between the LED lamps and tulip bulbs was 30 cm and the bulbs were kept in the cold storage for 35 days before being planted in a field at a depth of 10 cm with spacing of 15x15 cm. The sprouting rate was determined 15 days after the bulbs were planted. When over 50% of tulip flowers of each variety had bloomed (40 days after planting for 'Apeldoorn' and 46 days after planting for 'Ronaldo'), the flower diameters, flower heights, and plant heights were measured on the same day and at the same time across all treatments (see Figure 3). 55–57 days after planting the tulip bulbs, the fresh weights of the flowers, leaves, and bulbs were recorded immediately after harvest using a precision scale. The plants were kept in an oven at 65°C for 48 h, after which the dry weights of the flowers, leaves, and bulbs were recorded. Once the tulips had flowered and the green accents had dried, the remaining bulbs were removed from the plots. Root parts were washed with water and cleaned from the soil and measurements were taken.

Bud diameter (cm) Bud length (cm) Flower diameter (cm) Flower length (cm)

**Figure 3**. Bud and flower measurements

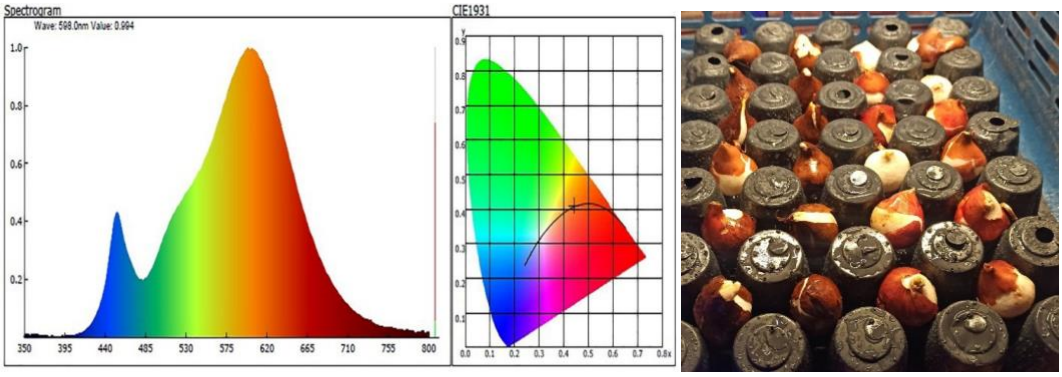


**Figure 4**. Wavelength, relative intensity, and CIE1931 value of yellow LED light applied to tulip bulbs (67.765 PPFD (umol/m$^2$/s))

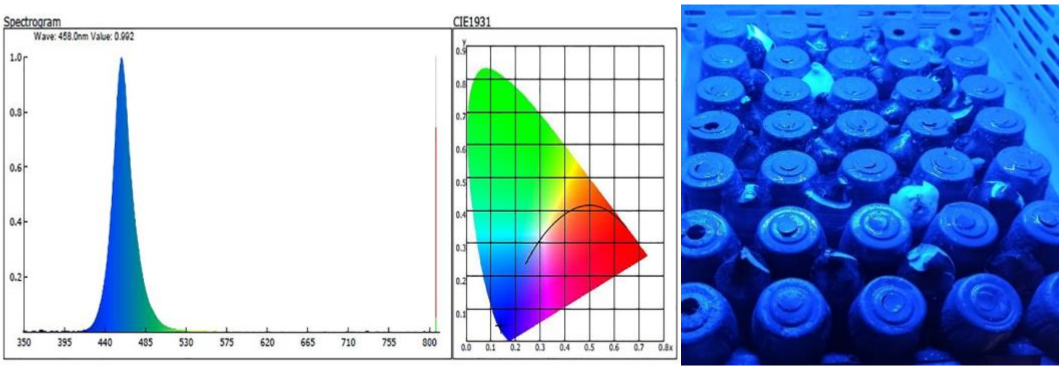


**Figure 5.** Wavelength, relative intensity, and CIE1931 value of blue LED light applied to tulip bulbs (61.284 PPFD (umol/m$^2$/s))

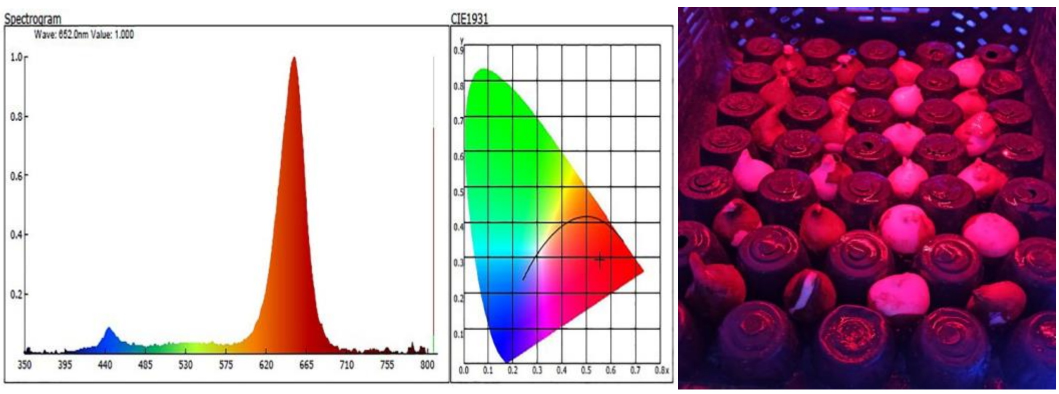


**Figure 6.** Wavelength, relative intensity, and CIE1931 value of red LED light applied to Tulip bulbs (0.991 PPFD (umol//s))

### Statistical analyses

This study had to "randomized plots experimental design" with 3 replications and 12 bulbs in each replicate. The obtained data were first analyzed with ANOVA conducted using the JUMP statistical program. Then the groups formed according to the differences were determined by the LSD test. The effects of LED colors were evaluated separately using correlation analysis. The positive and negative effects of blue, red, and yellow LED colors on the plant were examined. All statistical analyses were performed using a significance level of $p < 0.05$, and $p<0.01$ the graphs were created using JUMP version 18.

## RESULTS AND DISCUSSION

The effects of LED light applied to the tulip bulbs are summarized in Tables 1 and 2.

**Table 1.** Effects of LED lights applied to tulip bulbs.

| Factors | Sprouting rate (%) | Bud diameter (cm) | Bud length (cm) | Flower diameter (cm) | Flower length (cm) | Number of leaves (n) | Plant height (cm) | Flower stalk thickness (mm) |
|---|---|---|---|---|---|---|---|---|
| Cultivar | | | | | | | | |
| Apeldoorn | 98.80 a | 1.89 | 4.74 a | 7.97 a | 6.01 a | 4.07 a | 55.0 a | 23.0 a |
| Ronaldo | 87.19 b | 1.87 | 4.23 b | 5.89 b | 5.03 b | 3.73 b | 47.1 b | 21.1 b |
| P>0.05 | 0.00** | ns | 0.00** | 0.00** | 0.00** | 0.00** | 0.00** | 0.00** |
| LSD | 1.74 | 0.73 | 1.17 | 3.42 | 2.04 | 0.13 | 1.40 | 0.59 |
| Duration | | | | | | | | |
| 2 hours | 91.54 b | 1.88 | 4.50 | 7.08 | 5.54 ab | 3.84 | 51.7 a | 21.87 |
| 4 hours | 92.70 b | 1.83 | 4.43 | 6.68 | 5.34 b | 4.03 | 49.8 b | 22.16 |
| 6 hours | 94.75 a | 1.93 | 4.53 | 7.03 | 5.67 a | 3.84 | 51.5 a | 22.31 |
| P>0.05 | <0.01* | ns | ns | ns | <0.01* | ns | 0.02* | ns |
| LSD | 1.81 | 0.90 | 1.19 | 3.54 | 2.12 | 0.17 | 1.44 | 0.70 |
| LED illumination | | | | | | | | |
| Control | 90.44 b | 1.79 | 4.39 | 7.18 | 5.65 | 3.83 | 53.0 a | 22.38 |
| Red | 94.66 a | 1.90 | 4.39 | 6.76 | 5.52 | 3.84 | 49.2 c | 21.70 |
| Blue | 93.22 a | 1.92 | 4.52 | 6.70 | 5.43 | 3.94 | 50.8 bc | 22.40 |
| Yellow | 93.66 a | 1.91 | 4.46 | 7.09 | 5.47 | 4.00 | 51.1 c | 21.98 |
| P>0.05 | <0.01* | ns | ns | ns | ns | ns | <0.00* | ns |
| LSD | 2.09 | 1.04 | 1.38 | 4.08 | 2.46 | 0.19 | 1.67 | 0.82 |
| C x D | * | ns | ns | ns | ns | ns | ns | * |
| C x L | ns | ns | ns | ns | ns | * | ns | * |
| D x L | ns | ns | ns | ns | ns | ns | * | ns |
| C x D x L | ns | ns | ns | ns | ns | ns | ns | ns |

Small letters in the same column indicate a significant difference according to the LSD test, * and ** indicate a significant difference ($p<0.05$ and $p<0.01$, respectively). ns= not significant. C= cultivar. D= duration. L= LED illumination. LSD=least significant difference test.

### Sprouting rate

The results of ANOVA analysis of sprouting rate revealed significant differences in variety ($p < 0.01$), duration ($p < 0.05$) and LED illumination ($p < 0.05$). The highest average sprouting rate (98.80%) was observed in 'Apeldoorn' tulips, while the lowest average (87.19%) was documented in 'Ronaldo' tulips. Furthermore, the 6-h LED light application gave the best results. Red, blue, and yellow LED applications showed positive results in sprouting rate compared to the control application (Table 1). These findings are largely consistent with previous research: a previous study showed that the bulbs had good sprouting rates ('Oxford': 100%, 'Ballerina': 96%, and 'Apeldoorn': 98%) (Shah et.al., 2023).

Measurements started with the bud formation, which is the precursor of flowering, and the color of the buds.

### Bud diameter

For the measurements of tulip cultivars grown in different wavelengths of LED light treatment and for various durations, variety ($p < 0.01$) and all interaction factors were not significant ($p < 0.01$) for bud diameter (Table 1).

**Bud length**

The results of ANOVA analysis of bud length showed, significant differences between the two varieties ($p < 0.01$). Specifically, 'Apeldoorn' tulips (4.74 cm) had an average longer bud length than 'Ronaldo' tulips (4.23 cm; Table 1). The fact that 'Apeldoorn' showed higher values than 'Ronaldo' can be attributed to the genetic differences between these two varieties.

**Flower diameter**

The results of ANOVA analysis of flower diameter showed significant differences between the two varieties ($p < 0.01$). 'Apeldoorn' (7.97 cm) had flowers with a significantly larger average diameter than 'Ronaldo' (5.15 cm; Table 1). The fact that 'Apeldoorn' showed higher values than 'Ronaldo' can be attributed to the genetic differences between these two varieties.

**Flower length**

The results of ANOVA analysis of flower length showed that variety and duration were significant factors affecting flower length for tulip varieties grown under LED light of different wavelengths ($p < 0.01$ and $p < 0.05$, respectively, see Table 1). 'Apeldoorn' (6.01 cm) had a greater average flower length than 'Ronaldo' (5.03 cm). Furthermore, 6-h LED light application produced the longest stems. Accordingly, 'Apeldoorn' with larger flowers can be used when larger commercially attractive flowers are desired.

**Number of leaves**

The results of ANOVA analysis revealed that variety ($p < 0.01$) and LED treatment ($p < 0.05$) were significant factors affecting in the number of leaves (see Table 1). Specifically, the results showed that 'Apeldoorn' had more leaves (n=4.07) than 'Ronaldo' (n=3.73). For LED treatment, results were with blue LED light treatment giving 4.27 leaves for 'Apeldoorn' tulips. For 'Ronaldo' tulips, the number of leaves was the lowest with blue light (n=3.61). Therefore, the data suggest that the use of LED light with the same wavelengths causes different results depending on the tulip variety.

Similarly, in a study that examined the growth performance of lettuce (*Lactuca sativa var. crispa* L.. 'frillice') plants under glass greenhouse conditions with 460 nm blue and 630 nm red LED light, Inho et al. (2007) concluded that red-orange light was effective in increasing biomass accumulation. Noting that lettuce growth parameters could be improved with a complementary spectrally adapted LED lighting system, they authors reported that the addition of a very small amount 594 nm yellow light in addition to blue and red light promoted biomass accumulation and increased the number of leaves. In a similar study, the number of tulips leaves was 3.1-3.4 from all light treatments and there was no significant effect of light quality (Roh and Yoo, 2023).

**Plant height**

Variety, treatment, and duration factors significantly affected plant height ($p < 0.01$, $p < 0.01$, and $p < 0.05$, respectively, see Table 1), 'Apeldoorn' tulips had a plant height of 55 cm, which is greater than the variety standard of 45-50 cm, while 'Ronaldo' tulips had a plant height of 47.1 cm within the standard range of 45-50 cm. Analysis of this data shows positive results for plant height, for 'Apeldoorn' tulips, which is an important criterion for cut flower yield.

Considering the averages for treatment factors regarding tulips plant height, the control treatment (without additional lighting) produced an average plant height of 53 cm. Yellow LED treatment produced an average plant height of 51.1 cm, blue LED produced an average plant height of 50.8 cm, and red light procuded an average plant height of 49.2 cm. Based on these data, it was concluded that applying LED lights to buds was not effective in increasing tulips plant height. Similarly, previous studies showed that supplementing natural lighting did not influence the total plant height of of 'Kung Fu' and 'Strong Love', and increased plant height of 'Strong Gold' and 'Surrender'(Treder et al., 2025). In another study, the 'Princess Catharina-Amalia' tulip variety was subjected to various light treatments, including white, blue, and red light, as well as darkness. The data showed that average plant height increased under blue light and dark conditions (Amiri et. al., 2018). In conclusion, exposure of UV-A, blue, red, and far-red promotes extension growth in tulips. The most effective light was found to be FR (Far-Red). The effect of the long day treatment was found to vary according to growing temperatures (Hanks and Rees, 1979).

Similar studies revealed that the shortest tomato seedlings were observed grown under red light, while the tallest seedlings were reportedly obtained growing under daylight (Sarikurt and Sessiz, 2025). Average stem elongation in *Hydrilla verticillata* was greater with green light than with white, blue, or red light, with the shortest stem elongation from red light treatment (Van et al., 1977). Also, in *Dieffenbachia maculate*, *Ficus elastica*, *Tagetes erecta*, and *Salvia splendens*, average plant height was greater due to greater internode elongation with blue light compared with red light (Heo et al. 2002; Kim et al. 2013a, b). Conversely, for bulbous plants, cut freesia 'Yvonne' average plant height was greater with red light treatment than blue light (Lee and Hwang, 2014). Yet another relevant study showed that red light increases plant height by promoting stem elongation, whereas blue light inhibits stem elongation (Baraldi et al., 1995). The in vitro regeneration and growth of *Lilium* oriental hybrid 'Pesaro' was enhanced with blue plus red LED light compared with red LED light alone. Overall, the effect of light quality on plant height differs depending on the plant type.

### Flower stalk thickness

Variety, variety*duration and variety*treatment interactions significantly affected flower stalk thickness ($p < 0.01$, $p < 0.05$, and $p < 0.05$, respectively, see Table 1). ‘Apeldoorn’ variety had an average thicker flower stalk (23.1 cm) than the ‘Ronaldo’ (21.1 mm), meaning that the flowers can stand more upright when used as cut flowers.

For variety*treatment ‘Apeldoorn’ tulips with red and blue light treatments had an average stalk thickness of 23.3 mm and 23.1 mm, respectively, whereas ‘Ronaldo’ tulips had an average stalk thickness of 22.7 mm with control treatment.

For cultivar*duration, the best result was observed in ‘Apeldoorn’ tulips with 4 h of treatment at 23.6 mm average stalk thickness and 6 h resulting in 23.0 mm average stalk thickness. For ‘Ronaldo’ tulips, average flower stalk thickness was the lowest at 20.6 mm with 2 h of light treatment. As such, it would be useful to test the treatment duration for specific cultivars. According to Treder et al., (2025), the 'Surrender' tulips was reported to show increased average stalk diameter by 0.3 cm when grown under LED light for 8 h, compared to control plants.

Negative correlation coefficient indicates that as the first variable increases, the second variable decreases, and as the first variable decreases, the second variable increases. Positive correlation coefficient indicates that as the first variable increases, the second variable also increases, and as the first variable decreases, the second variable also decreases. The sign of the correlation coefficient (- or +) only indicates how the variables move in relation to each other. The correlation coefficient is the strength of the relationship between two variables, and as it approaches 1, the strength of the relationship between the two variables increases (0.00-0.03=weak, 0.04-0.06=moderate, 0.07-1=strong) (Bewick et.al., 2003).

When the data is examined, negative correlation is shown in blue and positive correlation in red. If the correlation coefficient is weak, it is indicated in light blue, and if it is strong, it is indicated in dark blue. If the correlation coefficient is weak, it is indicated in light red, and if it is strong, it is indicated in dark red (Figure 7-9).

‘Apeldoorn’ tulips, the highest negative correlation was observed between bud diameter and number of leaves. When evaluating the highest and lowest correlations, and positive and negative data, we found that the greatest positive correlation was between bud diameter and bud length after the 2 h treatment, while the greatest negative correlation was between bud diameter and number of leaves. Furthermore, we also observed that the greatest positive correlation was between bud diameter/length and flower length in the green LED treatment, while the greatest negative correlation was between bud diameter and number of leaves. Therefore, red and blue LED applications, as well as control applications, can be used to take advantage of positive developments.

**‘Apeldoorn’** **‘Ronaldo’**

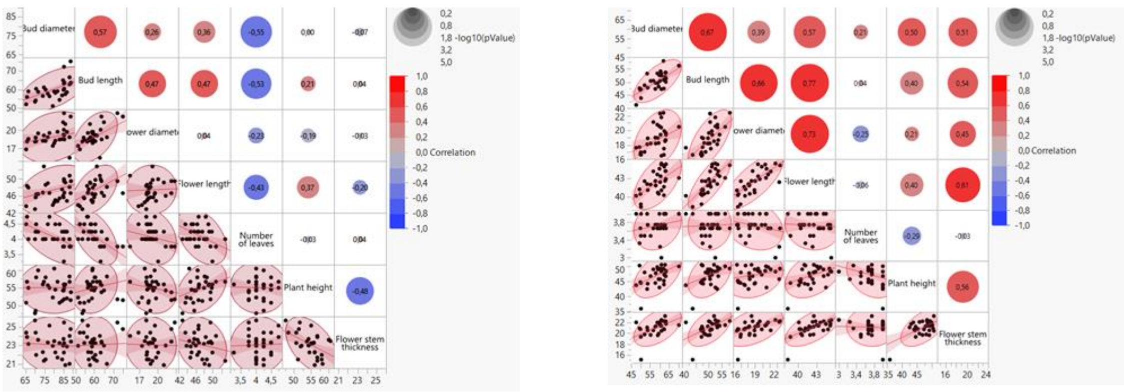


**Figure 7.** Cultıvar correlation

**2 hours** **4 hours** **6 hours**

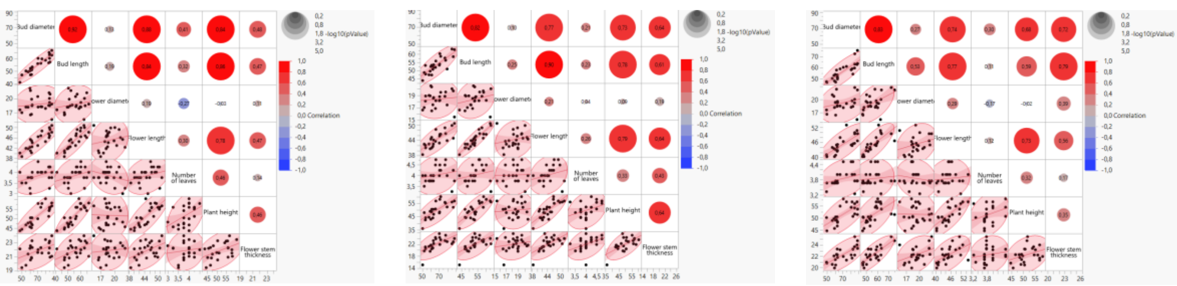

**Figure 8**. Duration correlation

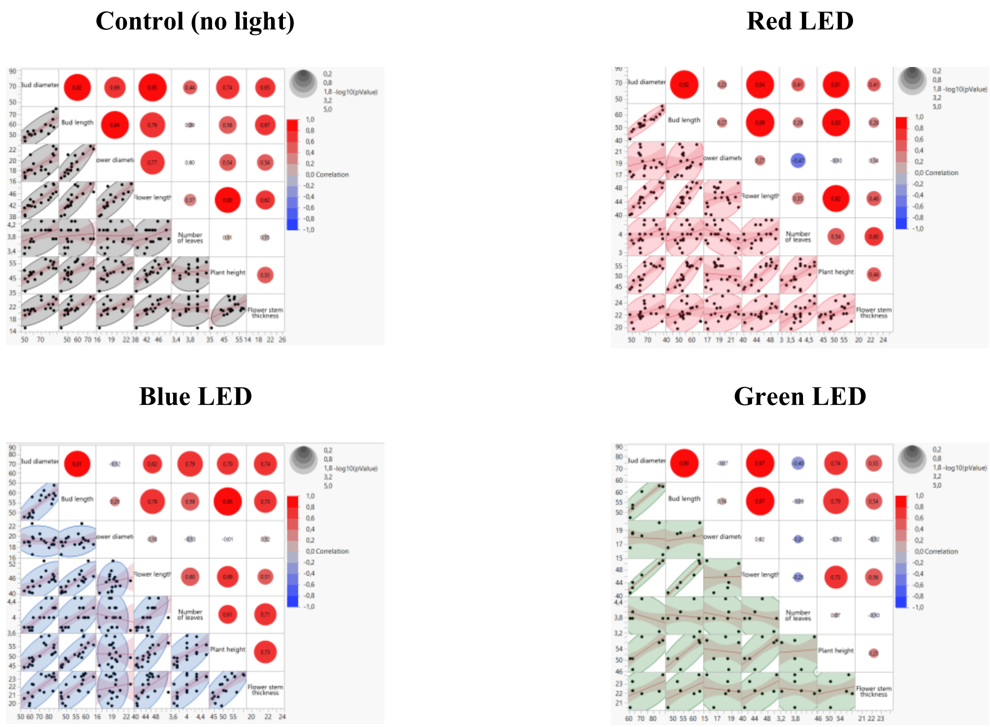


**Figure 9.** LED illumination correlation

**Table 2.** Effects of LED light on the fresh  and dry weights of petal, leaf, and bulb

| Factors | Petal fresh weight (g) | Leaf fresh weight  (g) | Bulb fresh weight (g) | Petal dry weight (g) | Leaf dry weight (g) | Bulb dry weight (g) |
|---|---|---|---|---|---|---|
| Cultivar | | | | | | |
| Apeldoorn | 2.17 b | 5.71 a | 1.07 b | 0.21 b | 0.57 | 0.23 b |
| Ronaldo | 2.43 a | 4.55 b | 3.11 a | 0.29 a | 0.54 | 0.62 a |
| P>0.05 | <0.01* | <0.01* | 0.00** | 0.00** | ns | 0.00** |
| LSD | 0.13 | 0.60 | 0.53 | 0.01 | 0.05 | 0.16 |
| Duration | | | | | | |
| 2 hours | 2.25 | 5.13 | 2.11 | 0.24 | 0.55 | 0.46 |
| 4 hours | 2.36 | 5.40 | 1.90 | 0.25 | 0.58 | 0.38 |
| 6 hours | 2.28 | 4.86 | 2.25 | 0.25 | 0.52 | 0.45 |
| P>0.05 | ns | ns | ns | ns | ns | ns |
| LSD | 0.14 | 0.65 | 0.56 | 0.01 | 0.08 | 0.17 |
| LED illumination | | | | | | |
| Control | 2.25 | 5.51 | 1.68 | 0.24 | 0.60 | 0.31 |
| Red | 2.36 | 4.87 | 2.58 | 0.26 | 0.53 | 0.52 |
| Blue | 2.31 | 5.21 | 2.12 | 0.25 | 0.56 | 0.43 |
| Yellow | 2.28 | 4.93 | 1.97 | 0.24 | 0.53 | 0.44 |
| P>0.05 | ns | ns | ns | ns | ns | ns |
| LSD | 0.17 | 0.73 | 0.65 | 0.02 | 0.08 | 0.19 |
| C x D | ns | ns | ns | ns | ns | ns |
| C x L | ns | ns | ns | ns | ns | ns |
| D x L | ns | ns | ns | ns | ns | ns |
| C x D x L | ns | ns | ns | ns | ns | ns |

Small letters in the same column indicate a significant difference according to the LSD test. * indicates a significant difference (*p<0.05*) SE= standard error. ns= not significant. C= cultivar. D= duration. L= LED illumination. LSD=least significant difference test.

**Petal fresh weight**

The results of ANOVA for petal fresh weight showed that variety was a significant factor ($p < 0.01$) and that ‘Ronaldo’ tulips had heavier petals (2.43 g) than ‘Apeldoorn’ tulips (2.17 g; see Table 2).

**Leaf fresh weight**

Similarly, the results of ANOVA for leaf fresh weight revealed that variety significantly affected leaf weight, with ‘Apeldoorn’ tulips having heavier leaves (5.71 g) than ‘Ronaldo’ tulips (4.55 g; $p < 0.01$, see Table 2). Therefore, ‘Apeldoorn’ tulips not only had a higher average number of leaves, but also a higher average fresh leaf weight.

**Bulb fresh weight**

ANOVA results showed that bulb fresh weight was significantly affected by variety ($p < 0.01$) and that ‘Ronaldo’ tulips (3.11 g) had on average heavier bulbs than ‘Apeldoorn’ tulips (1.07 g; see Table 2); thus, it is recommended to use ‘Ronaldo’ tulips if bulb production is preferred and bulbs are sold by weight.

**Petal dry weight**

Petal dry weight was significantly affected by variety ($p < 0.01$) and when the averages were taken into consideration, the ‘Ronaldo’ variety had a higher petal dry weight (0.29 g) than the ‘Apeldoorn’ variety (0.21 g; see Table 2). Similarly, He and Qin, (2020) found that supplemental LED lighting to natural SL increased leaf fresh and dry weights of hydroponically grown sweet potato (*I. batatas* var. Biru Putih) in the hot tropical greenhouse.

**Leaf dry weight**

Variety and all interaction factors did not significantly affect leaf dry weight (Table 2). Likewise, Masson et al. (1991) reported that $CO_2$ and light temperature together maintained the level of photosynthesis. However, unlike our study, the authors determined that additional lighting applied to tomato, broccoli, lettuce and celery seedlings increased the dry weight of shoots and roots.

**Bulb dry weight**

The results of ANOVA showed that variety significantly affected bulb dry weight ($p < 0.01$), with ‘Ronaldo’ tulips on average having heavier bulbs (0.62 g) than ‘Apeldoorn’ tulips (0.23 g; see Table 2).

Similarly, in a study on *in vitro* propagation of *chrysanthemum* plants, Kim et al. (2004) found the highest plant fresh and dry weight values for plants treated with fluorescent lamp with red and blue light. Similarly, for the micropropagation of gerbera, the most effective factors for plant fresh weight were white fluorescent lamp and 70% red + 30% blue LEDs applications (Zeng et al., 2011). The finding that white fluorescent lamp with red and blue light increases plant fresh and dry weights was also corroborated by Tanaka et al. (1998) in Cymbidium plants and by Lian et al. (2002) in Lilium plants. It is thought that red and blue light increase plant fresh and dry weights by promoting photosynthetic activity. In fact, in a study conducted by Shin and Murthy (2008), it was reported that red and blue light applications in *Doritaenopsis* plants increased chlorophyll, carotenoid, and carbohydrate (e.g., glucose, fructose, sucrose and starch) content in leaves more than other applications. Furthermore, chlorophyll content was the highest with 70% red + 30% blue LEDs application in strawberry plants illuminated with different light colors (Nhut et al., 2003).

## CONCLUSION

The results of the present study revealed that ‘Apeldoorn’ and ‘Ronaldo’ tulips bloomed on the targeted date. Greater bud length, larger flower diameter, greater flower length, largest number of leaves, tallest plant height, greatest flower stalk thickness, and greatest leaf fresh weight were observed in 'Apeldoorn' tulips. However, earliest sprouting rate, greatest petal fresh weight, greatest bulb fresh weight, greatest petal dry weight, and greatest leaf dry weight were observed in 'Ronaldo' tulips. There was no statistical differences between either of the cultivars or interactions in terms of bud diameter or leaf dry weight.

Based on the study results, it is evident that the LED wavelengths applied to tulip bulbs do not harm the bulbs. However, it remains unclear whether the differences in the results are due to the fact that ‘Apeldoorn’ is a Darwin hybrid type and ‘Ronaldo’ is a Triumph type. Further research is also needed to determine the effects of LED applications. In future studies, it is recommended to use tulip varieties of the same type and to test different LED applications or their combinations.

**Ethical Statements and Declarations**

**Conflict of Interest**

The author declares that there is no conflict of interest.

**Author Contribution**

The author solely conceived, designed, and conducted the study, analyzed the data, and wrote the manuscript.

Ethics Committee Approval Is Not Required

**Data Availability**

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Generative AI Statement**

The authors declare that no generative artificial intelligence tools were used in the preparation of this manuscript.

**REFERENCES**


Amiri, A. Kafi, M., Kalate-Jari1 S. and M. Matinizadeh. (2018). *Tulıp* Response To Dıfferent Lıght Sources. *The Journal of Animal & Plant Sciences,* 28(2): 2018, Page: 539-545 ISSN: 1018-7081

Baraldi, R.; Bertazza, G.; Bogino, J.; Luna, V.; Bottini, R. (1995). Effect of Light Quality on *Prunus Cerasus* II. Changes in Hormone Levels in Plants Grown under Different Light Conditions. *Photochem. Photobiol.,* 62, 800–803.

Bewick, V., Cheek, L., & Ball, J. (2003). Statistics review 7: Correlation and regression. *Critical care* (London, England), 7(6), 451–459. https://doi.org/10.1186/cc2401

Criley, R.A. (2011). Blueprınt Programmıng For Year-Around Forcıng Of *Curcuma Alısmatıfolıa*, *Acta Horti,* 1000 (2011), pp. 209-216. https://doi.org/10.17660/ActaHortic.2013.1000.27

De Hertogh, A. A., Le Nard, M. (1993). Wild production and horticultural utilization of flower bulbs. *Elsevier Science Publishers*, Cap, 2., Amsterdam.

Gezgin, B., (2007). The Effects of Different Pot Sizes on Tulip Bulb Formation and Characteristics in Ring Culture. Ankara *University Institute of Science and Technology,* Master's Thesis, Ankara.

Gruszecki, W.I., Luchowski, R., Zubik, M., Grudzinski, W., Janik, E., Gospo-darek, M., Goc, J., Gryczynski, Z., Grycynski, I. (2010). Blue-light-con- trolled photoprotection in plants at the level of the photosynthetic antenna complex LHCII. J *Plant Physiol* 167:69-73. https://doi.org/10.1016/j.jplph.2009.07.012

Hagiladi, A., Umiel, N., Yang, X. (1996). *Curcuma alismatifolia*. II. Effects of temperature and daylength on the development of flowers and propagules. *Acta Horti.,* 430, pp. 755-761. https://doi.org/10.17660/ActaHortic.1997.430.120

Hanks, G. R., Rees, A. R. (1979). Photoperiod and tulip growth. *Journal of Horticultural Science*, 54(1), 39–46. https://doi.org/10.1080/00221589.1979.11514846

He, J., Qin, L. (2020). Growth and photosynthetic characteristics of sweet potato (*Ipomoea batatas*) leaves grown under natural sunlight with supplemental LED lighting in a tropical greenhouse. *Journal of plant physiology*, 252, 153239. https://doi.org/10.1016/j.jplph.2020.153239

Heo, J., Lee, C., Chakrabarty, D., Paek, K. (2002). Growth responses of marigold and salvia bedding plants as affected by monochromic or mixture radiation provided by a light-emitting diode (LED). *Plant Growth Regul* 38:225-230. https://doi.org/10.1023/A:1021523832488

Heo, J.W., Lee, C.W., Murthy, H. (2003). Influence of light quality and photoperiod on flowering of Cyclamen persicum Mill. cv. 'Dixie White'. *Plant Growth Regulation* 40, 7–10 (2003). https://doi.org/10.1023/A:1023096909497

Heo, J.W., Lee, Y.B., Lee, D.B., Chun, C.H. (2009). Light quality affects growth, net photosynthetic rate, and ethylene production of ageratum, african marigold, and salvia seedlings. *Kor J Hortic Sci Technol* 27:187-193. https://doi.org/10.3389/fpls.2024.1356257

Hongpakdee, P., Ohtake, N., Sueyoshi, K., Ohyama, T., Ruamrungsri, S. (2010). Effects of Low Night Temperature and Short Day Length on Some Phytohormones and Nutrient Status in *Curcuma alismatifolia* Gagnep. *Thai Journal of Agricultural Science*, 43(3): 163-173.

Inho, P., Lukkala, R., Sarkka, L., Tetrı, E., Tahvonen, R. And Halonen, L. (2007). Evaluation of Lettuce Growth Under Multi-Spectral-Component Supplemental Solid State Lighting in Greenhouse Environment. *International Review of Electrical Engineering* (IREE), (2): 6. https://www.researchgate.net/publication/299207189

Jeong, S.W., Park, S., Jin, J.S., Seo, O.N., Kim, G.S., Kim, Y.H., Bae, H., Lee, G., Kim, S.T., Lee, W.S., Shin, S.C. (2012). Influence of four different light-emitting diode lights on flowering and polyphenol variations in the leaves of chrysanthemum (*Chrysanthemum morifolium*). *J Agric Food Chem* 60:9793-9800. https://doi.org/10.1021/jf302272x

Johkan, M., Shoji, K., Goto, F., Hashida, S., Yoshihara, T. (2010). Blue light- emitting diode light irradiation of seedlings quality and growth after transplanting in red leaf lettuce. *HortScience* 45:1809-1814. https://doi.org/10.21273/HORTSCI.45.12.1809

Kim, M.S., Chae, S.C., Lee, M.W., Park, G.S., Ahn, S.W. (2013a). The effect of LED light quality on foliage plants growths in interior environment. *J Environ Sci Inter* 22:1499-1508.

Kim, S.H., Heo, Y., Rhee, H.C., Kang, J.S. (2013b). Effect of LED light quality and supplemental time on the growth and flowering of impatiens. *Protec Hortic Plant Fac* 22:214- 219.

Kim, S.J., Hahn, E.J., Heo, J.W., Paek, K.Y., (2004). Effects of LEDs on net photosynthetic rate, growthand leaf stomata of chrysanthemum plantlets in vitro. *Scientia Horticulturae* 101, 143151. https://doi.org/10.1016/j.scienta.2003.10.003

Kodal, A., Sarıkamış, G., Şahin, Ö., & Demir, K. (2025). Salt stress response of cauliflower (*Brassica oleracea* var. botrytis) seedlings under different LED light wavelengths. *International Journal of Agriculture Environment and Food Sciences*, 9(2), 608-616. https://doi.org/10.31015/2025.2.34

Lambrechts, H., Rook, F., & Kolloffel, C. (1994). Carbohydrate Status of Tulip Bulbs during Cold-Induced Flower Stalk Elongation and Flowering. *Plant physiology,* 104(2), 515–520. https://doi.org/10.1104/pp.104.2.515

Lee, J.J., Hwang, J.H. (2014). Effect of day-length extension treatment using LED on growth and flowering of Freesia hybrid 'Yvonne'. *Kor J Hortic Sci Technol* 32:794-802. https://doi.org/10.7235/hort.2014.14080

Lian, M.L.,. Murthy, H.N., Paek, K.Y. (2002). Effects of light mitting diodes (LEDs) on the in vitro induction and growth of bulblets of *Lilium oriental* hybrid 'Pesaro'. *Scientia Horticulturae* 94, 365-370. https://doi.org/10.1016/S0304-4238(01)00385-5

Malta S. (2016). Effect of location, culture media and shading on growth and quality of tulip (*Tulipa gesneriana* L.). Gaziosmanpaşa University, Institute Of Natural Sciences, Department Of Horticulture, Master's thesis, 64 pages.

Masson, J., Tremblay, N. and Gosselin, A. (1991). Nitrogen Fertilization and HPS Supplementary Lighting Influence Vegetable Transplant Production. I. Transplant Growth. *J. Amer. Soc. Hort. Sci.* 116 (4): 594-598. https://doi.org/10.21273/JASHS.116.4.594

McNellis, T.W., Deng, X.W. (1995). Light control of seedling morpho- genetic pattern. *Plant Cell* 7:1749-1761. https://doi.org/10.1105/tpc.7.11.1749

Nhut, D.T., Takamura, T., Watanabe, H., Okamoto, K., Tanaka, M. (2003). Responses of strawberry plantlets cultured in vitro under superbright redand blue light-emitting diodes (LEDs). *Plant Cell, Tissue and Organ Culture* 73, 43-52. https://doi.org/10.1023/A:1022638508007

Poyraz, N., Yaşar, A. (2005). Ratio of fusarium rot on tulip bulbs and it's chemical control. Selcuk University, *Journal of Faculty of Agriculture*, 19 (37): (2005) 125-134

Roh, Y.S., Yoo, Y.K. (2023). Light quality of light emitting diodes affects growth, chlorophyll fluorescence and phytohormones of Tulip 'Lasergame'. *Hortic. Environ. Biotechnol*. 64, 245-255 (2023). https://doi.org/10.1007/s13580-022-00481-z

Ruamrungsri, S. (2015). The physiology of Curcuma alismatifolia Gagnep. As a basis for the improvement of ornamental production. *Eur. J. Hortic. Sci.,* 80 (6) (2015), pp. 316-321. https://doi.org/10.17660/eJHS.2015/80.6.7

Sarikurt, M. A., & Sessiz, A. (2025). Determination of the Effects of Different Light Colors on the Germination and Development of Tomato Seeds. *International Journal of Agriculture Environment and Food Sciences,* 9(3), 706-715. https://doi.org/10.31015/2025.3.8

Seelatlao, C., Dongsansuk, A., Isarangkool, N., Ayutthaya, S., Hongpakdee P. (2023). Evaluated crop water requirement of flowering potted *Curcuma* hybrid cv. "Doi Tung Red." *Acta Horti.,* 1404 (2023), pp. 157-162. https://doi.org/10.17660/ActaHortic.2024.1404.22

Shah, M.H., R.U Rehman, R.A. Shah, F. Batool, R. Rafique, M. Usman, S. Bibi, S. Yasin and S. Qamar. (2023). Growth and flowering responses of elite varieties of tulip (Tulipa gesneriana L.) in Rawalpindi climate zone. Sarhad Journal of Agriculture, 39(2): 552-557. https://dx.doi.org/10.17582/journal.sja/2023/39.2.552.557

Shao, M., Liu, W., Zha, L., Zhou, C., Zhang, Y., Li, B. (2020). Effects of constant versus fluctuating red-blue LED radiation on yield and qual- ity of hydroponic purple-leaf lettuce. *Hortic Environ Biotechnol* 61:989-997. https://doi.org/10.1007/s13580-020-00285-z

Shin, K. S., Murthy, H. N. (2008). The effect of light quality on the growth and development of in vitro cultured Doritaenopsis plants. *Acta Physiol Plant* 30, 339-343. https://doi.org/10.1007/s11738-007-0128

Sour, V., Dongsansuk, A., Ayutthaya, S.I.N., Panjama, K., Inkham, C., Ruamrungsri, S., Hongpakdee, P. (2025). Extended life span, improved flower qualities, and enhanced water use efficiency of potted Curcuma cv. 'Jasmine Pink' under off-season production by low R:FR light provided by incandescent as night break techniques. *Scientia Horticulturae,* Volume 350, 2025, 114320, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2025.114320

Tanaka, M., Takamura, T., Watanabe, H., Endo, M., Yanagi, T., & Okamoto, K. (1998). In vitro growth of Cymbidium plantlets cultured under superbright red and blue light-emitting diodes (LEDs). *Journal of Horticultural Science & Biotechnology*, 73(1), 39–44. https://doi.org/10.1080/14620316.1998.11510941

Treder, J., Kowalczyk, W., Sochacki, D., Skutnik, E., Rabiza-Świder, J., Staniuk, A., Połeć, A. (2025). Effects of supplemental lighting using LEDs on the quality of tulips forced hydroponically. *Acta Horticulturae,* 1435 (10), 2025, Pages 83-90. https://doi.org/10.17660/ActaHortic.2025.1435.10

Van, T.K., Haller, W.T., Bowes, G., Garrard, L.A. (1977). Effects of light quality on growth and chlorophyll composition in hydrilla. J Aquat Plant Manage 15:29-31 diodes (LEDs). *J. Hort. Sci. Biotechnol*. 73, 39-44

Xu, R.Y., Niimi, Y. (2008). Cold treatment affects microspore development and induces IAA production in pollen sacs in tulip, *Scientia Horticulturae,* Volume 115, Issue 2, 2008, Pages 168-175, ISSN 0304-4238, https://doi.org/10.1016/j.scienta.2007.08.014

Zheng, W., Li, G., He, S., Silva, J.T., & Tanaka, M. (2011). Effect of cold cathode fluorescent lamps on growth of *Gerbera jamesonii* plantlets in vitro. *Scientia Horticulturae,* 130, 482-484. https://doi.org/10.1016/j.scienta.2011.05.022