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Optimizing of the quality of rose grown with varying ratios and periods of Red: Blue light-emitting diodes in commercial greenhouse

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ABSTRACT

Purpose: This research investigated the effect of different regimes of supplementary LED light on physiological and morphological traits of two cultivars of cut Roses. **Research method:** In this study, treatments included cultivars (Allstar and Dolcevita) and nine light regimes including (Control, LED night from 5 pm to 7 am, LED day from 7 am to 5 pm, LED night day (24 hours light) and LED dark (24 hours, without sunlight) which were all applied in two intensities of 2000 and 4000 lux. **Findings:** The results showed that the LED light regime had a positive effect on morphological traits such as the number of buds and mean harvest, length, diameter and fresh weight of flowers. LED day 4000 lux improved bud diameter and mean harvest by 18% and 112% respectively compared with control in Dolcevita cultivar. The light regime also caused a significant improvement in physiological characteristics so that in Allstar cultivar LED day 4000 lux, chlorophyll a, b, total, and carotenoid were increased by 66%, 60%, 63%, and 64% respectively compared with control. The vase life in Allstar cultivar by LED night day 4000 lux intensity and Dolcevita cultivar by LED day 4000 lux were 44.5% and 133.2% higher than the control treatment, respectively. **Research limitations:** There was no limitation. **Originality/Value:** The results showed that LED night day with 4000 lux intensity had the best results in vase life in Allstar cultivar and LED day supplementary light with 4000 lux intensity increased the quantity and quality characteristics of roses.

INTRODUCTION

Rosa hybdria is one of the most popular cut flowers. Several elements influence the quality and postharvest life of roses after they have been cut (Shi et al., 2021). These factors are classified into two categories: preharvest and postharvest. The most important preharvest stage parameters that have a significant influence on appearance quality, physiological features, and vase life of flowers are irrigation conditions, mineral nutrients, and the amount and quality of light. Among these elements, light is crucial for floral quality, biosynthesis, and pigment content (Rasouli et al., 2015).

Livadariu et al. (2023) state that LED lighting has become more prevalent in the past few decades for the commercial breeding of various economically important species in horticulture and agriculture. LED lights are long-lasting, have high radiative efficiency, and switch quickly. Furthermore, they enable the selection and customization of output spectrum characteristics, which meet the demands of the plant and allow for high-quality harvests including antioxidant capacity (Carotti et al., 2021). In recent studies by Song et al. (2022), it has been reported that different light wavelengths have the ability to regulate various plant processes, including photosynthesis, germination, flowering, biomass accumulation, and phytochemical synthesis. Research indicates that red light plays a crucial role in the development of the photosynthetic apparatus and influences morphogenesis through light-induced transformations of the phytochrome system. On the other hand, blue light can impact chlorophyll biosynthesis, stomata opening, and photomorphogenesis (Song et al., 2022; Sakurako et al., 2021). As red and blue light are the primary absorption peaks of photosynthetic pigments in plant leaves, they have a significant impact on plant photosynthesis. However, it is important to note that a single red or blue light is insufficient for normal plant growth. Studies suggest that a specific proportion of red and blue light is necessary for optimal plant growth (Song et al., 2022).

The effect of light on the proportion of plant hormones is one of the processes in the effect of light on plant growth and morphology. Kurepin et al. (2010) discovered that long-term culture under changing light conditions has an effect on internal hormone levels, particularly auxin, and induces homeostasis. Furthermore, it appears that high-intensity blue light damages or does not synthesize auxin. According to Cioć et al. (2022), the application of red and red:blue light in gerbera flowers led to a decrease in tissue auxin levels. In contrast, the use of blue LED light resulted in a lowered the shoot multiplication rate and their height, but it induced the highest content of gibberellins in the final stage of the culture.

According to Alsanius et al. (2017), red LED light 80% + blue 20% with 16 hours of illumination and intensity of 7000 lux improved sunflower plant height and stem diameter. Schroeter-Zakrzewska and Pradita (2021) discovered that Chrysanthemum plants grown under red + blue light had the highest leaf greenness index (SPAD) value and the shortest cuttings with the longest roots. Additionally, white + blue light significantly affected most of the growth parameters, except for plant height and the number of leaves.

Cut flower post-harvest senescence is a dynamic process involving physiological and biochemical changes that are governed by a cell death program. Carnation senescence's physiological and biochemical features have already been characterized, and conditions during mother plant growth, storage and handling, environment, and phytohormones all play roles in senescence regulation (Aalifar et al., 2020). Postharvest or vase life as a commercial attribute impacts the market's flexibility at any given time, particularly for cut flowers. The limited vase life of cut rose flowers is related to physio-chemical processes that influence aging. Water loss and wilting during transit have a significant impact on these characteristics.

Water scarcity and the resulting premature senescence result in poor cut flower quality and market loss, according to numerous reports (Alaey et al., 2011).

Optimizing the quality of roses in commercial greenhouses through different ratios and durations of LED lighting is an important research topic in agriculture today. As it has a significant effect on the quality and performance of roses in greenhouses. By determining the optimal ratio and duration of red:blue LED lighting, growers can ensure that their roses receive the right amount and type of light, which can lead to improved quality, marketability, and vase life. This, in turn, can lead to a reduction in energy consumption and an increase in profitability for producers. In this regard, the present research investigates the influence of supplemental LED light on the physiological and morphological features of two cut rose cultivars, “Allstar” and "Dolcevita," in a commercial greenhouse under different LED light regimes. The study also examines the effect of pretreatment of roses with LED on their vase life. The findings of this research can provide valuable insights into the optimal lighting conditions for rose growth and inform future research and innovation in the field.

MATERIALS AND METHODS

Culture conditions and light treatments

This experiment was conducted in the Sivan Energy commercial rose greenhouse in Dahagan, Isfahan province, as a factorial experiment in the form of a completely randomized design (CRD). This study included three replications and focused on two rose cultivars, Allstar and Dolcevita. Allstar and Dolcevita rose plants were imported from the Dutch company De Ruiter, Amstelveen, and the Netherlands, whose standard morphological characteristics are shown in Table 1 according to the manufacturer's information. Then, the hydroponic bed was prepared and the rose bushes, which were approximately 25 cm in size and had 2-3 leaves, were planted in the perlite bed with a distance of 19 cm between the bushes. To start establishing the plants, they were watered for two weeks, and then NPK fertilizer (20-20-20) was given to the rose plants for one month and the plants were fed daily with the nutrient solution, the information of which is included in Table 2 (Nikbakht & Ashrafi, 2019)

Light regime treatments (red wavelength 60%+blue wavelength 40%) included 9 levels: Control (without using LED light), LED night (5 pm to 7 am) with two intensities of 2000 and 4000 lux+sunlight, LED day (7 am to 5 pm) with two intensities of 2000 and 4000 lux+ sunlight, LED day and night (24 hours of light) with two intensities of 2000 and 4000 lux+sunlight and LED dark (24 hours without sunlight) with two intensities of 2000 and 4000 lux (Table 3).

Five months after the growth and full establishment of the plants, LED lamps were placed at a distance of approximately one meter from the substrate to provide the desired light intensity on the leaf surface. The light intensity of 2000 (35μmolm^{-2} s^{-1}) and 4000 (75μmolm^{-2} s^{-1}) lux was adjusted by adjusting the amount of use of these lamps in the panels, and the wavelength of the lamps used was 660 (red), and 460 nm (blue) (Fig. 1 and Fig. 2). The control treatment received only sunlight and no LED light was applied. In the LED night treatment, LED treatments applied during the day and night, the light intensity of the LED lamps was 2000 and 4000 lux along with the sunlight intensity. But in the LED dark treatment, the plant environment was darkened with black covers to minimize the effect of sunlight intensity, then the light regimes were applied on Allstar and Dolcevita rose cultivars with three repetitions, each repetition including six rose bushes. The light treatments were applied for about three months and during this period we had six to seven peak harvests, where the measured parameters were obtained from the last harvest.

Table 1. Specifications of Allstar and Dolcevita cultivars in standard conditions.

Cultivar	Shape	Bud length (cm)	Stem length (cm)	Vase life (days)	Production in square meters per year (flower branch)
Allstar		5.4-5.5	40-60	10-12	180-220
Dolcevita		5-6	50-80	7-10	150-200

Table 2. Hydroponic nutrition solution formula in this experiment.

(μM)	Micro elements	(mM)	Macro elements
30-50	Fe	11/25-11/5	NO_3
5-6	Mn	1-1/5	NH_4
4-5	Zn	1/25-1/3	H_2PO_4
30-40	B	4/5-5	K
0/60-0/75	Cu	3/5-4	Ca
0/5-0/6	Mo	1/25-1/3	Mg
1/6	EC	1/25-1/3	SO_4
5/5	pH	1/25-1/3	HCO_3

Table 3. Introduction of experimental treatments.

Cultivar	Light regimes
Allstar/Dolcevita	Control (Without LED light)
	LED night(5 pm to 7 am) with 2000 lux intensity + sunlight
	LED night(5 pm to 7 am) with 4000 lux intensity + sunlight
	LED day (7 am to 5 pm) with 2000 lux intensity + sunlight
	LED day (7 am to 5 pm) with 4000 lux intensity + sunlight
	LED night day (24 hours light) with 2000 lux intensity + sunlight
	LED night day (24 hours light) with 4000 lux intensity + sunlight
	LED Dark (24 hours, without sunlight) with 2000 lux intensity
	LED Dark (24 hours, without sunlight) with 4000 lux intensity

LED include red wavelength 60% + blue wavelength 40%

Fig. 1. LED lamps installed in the greenhouse.

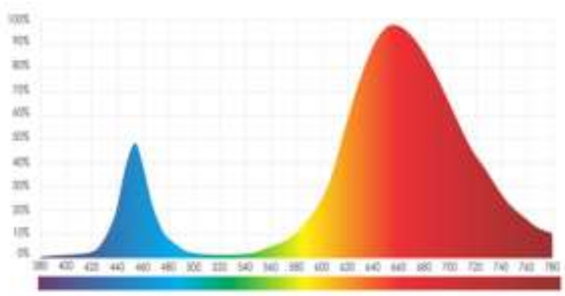

Fig. 2. Wavelengths used in LED boards.

Harvesting and measuring the growth parameter

Throughout the experimental stages from February 15 for 10 weeks in order to check the effect of the treatments, the number of flowers that were produced in each treatment from each plant was picked and recorded. The number of buds was counted one week after the treatment, regardless of whether the resulting buds changed into harvestable flowers, and the counts were averaged for each repetition individually and recorded weekly for ten weeks, with the results given for each replication after averaging. The length of the stem from under the sepal to the cut point (ten weeks) was also measured with a ruler and reported for each replication.

For each repeat of three flowers, the weight of cut flowers was measured in three phases at two-week intervals using a scale with an accuracy of 0.01 g for 30 cm long cut flowers, and its size was measured for each repetition and reported after averaging. After weighing three flowers for each replication, they were packaged in paper envelopes and placed in a 70-degree oven for 48 hours to determine the dry weight of cut flowers with a length of 30 cm. The number of leaves on each bloom was counted in each repeat and averaged for each repetition, and this experiment was repeated ten times with a one-week interval. The leaf area of the plants was measured using an Alborz Andisheh Technologies Co. leaf area measurement device, model Winarea-UT-11, in each replication of 8-10 leaves.

Physiological factors

A sample of 5 g of the tissue was homogenized with 80% acetone; the residue was filtered and adjusted to 10 mL; the absorbance reading was done at 476, 646, and 663 nm using the spectrophotometer (Model UV 160A- Shimadzu Corp., Kyoto, Japan) (Arnon, 1949). The content of carotenoids was calculated based on the formula (1) presented by Pérez -Grajales et al. (2019).

$$\text{Total chlorophyll} = \text{Chlorophyll a} + \text{Chlorophyll b}$$

$$\text{Carotenoids} = 100(A476) - 3.27(\text{mg/g Chl. a}) - 104\ (\text{mg/g Chl. b})/227 \qquad (1)$$

The spectrometric method by Rapisarda et al. (2000) was used to determine anthocyanin. Fresh leaves (1.0 g) were crushed with 20 mL alcohol (60 %; pH = 3.0) and heated the samples on hot water for 2 h; after cooling the samples certain volume of sample solution was used for reading at 535 nm anthocyanin content (mg/100 g FW).

The chlorophyll index of mature plant leaves was used by the chlorophyll meter (SPAD-502 plus, Japan). For this goal, three readings were carried out from each plant on three separate leaves (a total of 9 readings per replicate), and then the average was registered (Dezhabad & Haghighi, 2020). Maximum photochemical quenching Fv/Fm was measured by chlorophyll fluorescence (model OS-30, Minolta Corp). The portable fluorescence monitoring system (Hansatech Instruments LTD RS232) was used for chlorophyll fluorescence determination. The instrument clamp was placed on each leaf for 30 min to complete the dark adaptation. The initial (F0), maximum (Fm), and maximum quantum efficiency of the photosystem-II (Fv/Fm) were reported according to Maxwell and Johnson (2000).

Vase life experiment

The appropriate flowers were selected early in the morning using sterilized scissors and immediately placed in water. They were then taken to Isfahan University of Technology and placed in a cold room at 4°C for 8 hours to absorb water and cool the flowers. The next morning, all flowers were cut at a distance of 30 cm from the end of the flower bud and immediately placed in 500 ml containers containing distilled water that had been disinfected with 70% alcohol at a temperature of 24±2°C and a humidity of 40±5%, and were kept in 13 hours of light and 11 hours of darkness.

To determine carbohydrates content, the method of Hedg and Hofreiter (1962) was used. In this way, 100 mg of the sample was placed in a boiling bath with 5 mL of 2.5 N hydrochloric acid for 3 hours. Then, a few drops of 2% sodium carbonate were added to each sample. Add 25 mL of distilled water to the resulting solution to reach a volume of 50 ml. 0.1 mL of the resulting solution was removed and made up to 10 ml with distilled water. In the next step, 2 mL of anthrone reagent was added to the solution and placed in a boiling water bath for 1 minute. Then the resulting solution was cooled at the laboratory temperature and its light absorption was read at 630 nm by a spectrophotometer model (Shimadzu UV106A) (Hedge & Hofreiter, 1962). The amount of carbohydrates in the studied sample was estimated in terms of mg/g of dry sample weight using a standard curve. 0, 0.2, 0.4, 0.6, 0.8, and 1 ml of standard were used to prepare the standard curve.

The vase life of the flowers was considered from the time of harvesting to the bending of the neck or falling of the petals and was expressed as a number of days (Shi et al., 2021).

The speed of flower opening was measured by calipers on days 0, 2, 5, and 8, and the maximum amount of flower opening was subtracted from the diameter of the flower on day 0 and divided by the number of days, which was calculated in millimeters per day.

Flower water content was obtained by dividing the difference between the heavier and dry weight of the flower by its heavier weight. This experiment was performed twice in two weeks and for each repetition, the calculation and its numbers were reported separately.

Statistical analysis

The study applied following a factorial experiment in a complete randomized design (CRD) with three replications. The data underwent analysis using SAS program version 9.1 (SAS Institute, Cary, NC). The data performed a two-way analysis of variance (ANOVA), and the means were examined for statistical significance using the least significant difference (LSD) test at a significance level of P<0.05. Principal component analysis (PCA) was carried out using Statgraphics Centurion, Version XVI.

RESULTS AND DISCUSSION

The results of variance analysis are presented in Table 4. The main effects are not shown due to the significance of the interaction effect and the rising length of the article.

Table 4. Analysis of variance of main and interaction effects of treatments.

Source	df	Bud number	Mean harvest weekly	Cut flower height	Bud length	Bud diameter	Number of leaves	Stem diameter	Flower quality
Cultivar	1	0.4877 n.s	0.09086 **	145.366 n.s	5.59185 **	1.70951 **	37.9178 **	0.03393 **	0.42934 n.s
Light	8	10.1285 **	0.20967 **	188.908 **	0.80121 **	0.34802 **	8.0516 **	0.3337 **	3.26838 **
Cultivar×Light	8	0.5771 **	0.05788 **	102.617 *	0.03617 *	0.0469 *	3.2455 **	0.00503 **	0.60103 *
Error	34	0.0889	0.01218	53.881	0.0362	0.02864	0.2841	0.0004	0.25421
CV		6.2	10.4	13.52	3.68	4.56	5.43	2.23	6.51

ns: not significant, * significant at P ≤0.05 and ** significant at P ≤0.01 probability level, df: degree of freedom.

Table 4. (*Continued*).

Source	df	Greenness	Chlorophyll fluorescence	Fresh weight of cut flowers	Dry weight of cut flowers	Leaf surface	Thrips pest	Chlorophyll a of leaves
Cultivar	1	433.217 **	0.00089 n.s	390.48 **	11.6111 * *	2.325E+10 n.s	0.0741 n.s	0.00258 n.s
Light	8	51.644 **	0.00263 **	299.717 **	10.1983 **	2.655E+10 *	20.713 **	0.01543 **
Cultivar×Light	8	15.011 **	0.00074 *	38.426 **	1.1937 **	2.700E+10 *	0.4907 *	0.01058 **
Error	34	3.769	0.0005	3.684	0.2004	2.64E+10	0.1991	0.00125
CV		3.87	2.9	4.8	6.42	4.56E+02	9.41	11.57

ns: not significant, * significant at P ≤0.05 and ** significant at P ≤0.01 probability level, df: degree of freedom.

Table 4. (*Continued*).

Source	df	Chlorophyll b of leaves	Total chlorophyll of leaves	Carotenoids of leaves	Anthocyanin of petal	Carbohydrate of leaves	Vase life	Speed of flower bud opening	Flower water content
Cultivar	1	0.00435 n.s	0.02664 n.s	0.00139 n.s	708460 **	0.21426 **	13.0046 **	0.1057 n.s	0.01051 n.s
Light	8	0.0068 **	0.10137 **	0.00728 **	3398 *	0.24455 **	9.3542 **	0.80612 **	1.19501 *
Cultivar×Light	8	0.00282 *	0.06262 **	0.0045 **	8603 **	0.02369 **	0.9421 *	0.30697 *	0.45356 *
Error	34	0.00149	0.00994	0.00056	1603	0.00705	0.509	0.16335	0.89472
CV		16.69	12.15	12.13	27.29	7.58	6.67	16.39	1.14

ns: not significant, * significant at P ≤0.05 and ** significant at P ≤0.01 probability level, df: degree of freedom.

The effect of LED on morphological factors of two rose cultivar

The number of buds, flower harvest (weekly), cut flower height, bud length, bud diameter

In the interaction effects of the light regime with the cultivar, the Allstar produced the most bud number in the LED day 2000 lux intensity treatment, which was 37% more than the control. Dolcevita produced the highest number of buds with LED night 4000 lux which was 42% more than the control (Table 5). A positive correlation was detected at the 1% level between bud number and bud length, diameter of bud, number of leaves, flower number, greenness, fresh weight, dry weight, carbohydrate, and vase life.

The results of study Park and Jeong (2020) indicated that a 4-h supplementation of blue light with a wavelength of 450 nm during the photoperiod increases flower bud formation in chrysanthemum. Light treatments were found to increase the amount of collected buds and flowers in this study. Heo et al. (2003) found that irradiating cyclamen (*Cyclamen persicum*) with red-blue light at a 1:1 ratio with a light intensity of 5500 lux for 12 hours can enhance the number of flower buds compared to the control and other monochromatic kinds, as well as make the blooms survive longer. On the facility for approximately 20 days longer than the control.

The interaction effect of light treatments with cultivar, the highest number of flowers harvested in Allstar was observed in LED dark 2000 lux treatment, which was 17% compared with the control. In the Dolcevita, the highest number of harvested flowers was observed in the treatment of LED day 4000 lux intensity, which increased by 105% compared to the control (Table 5). There is a positive correlation at the level of 1% with chlorophyll a, total chlorophyll, and relative water content at a 5% level, and a negative correlation was observed with thrips density index (was scored between lower 1 to higher 10 observation).

We can expect varied reactions in the formation of flowers in plants if we use different light spectrums and durations of light presence. The amount of internal auxin in plants can also be regulated by the quality of light. According to one study, the quality of light influences the activity of IAA oxidase and causes an increase in the length of roots and stems, which is most likely produced by a change in the amount of internal auxin in the plant (Iacona & Muleo, 2010). According to Hao et al. (2016), red-blue supplementary light at a ratio of 1:1 with a light intensity of 5000 lux on the cloud plant (Houstonianum cv. Blue Field Ageratum) increased the number of flowers. Gao et al. (2023) conducted an experiment which revealed a lower R:FR ratio of 54%:46% under natural light treatments compared to artificial light treatments. Interestingly, the high proportion of far-red light in natural light was found to promote the flowering number in *Crocus sativus* L. plants.

In the interaction effect of light treatment with cultivar, the highest cut flower height was observed in the Allstar cultivar in the treatment of LED dark 2000 Lux, which was 45% higher than the control. In the Dolcevita cultivar, the highest flower height harvested in LED night 2000 lux treatment was observed, which was a 40% increase in height compared with the control (Table 5). Thrips pest symptom and water content showed a positive and significant correlation at the 1% level, and with the weight, leaf area, and relative water content at the 5% level.

In the interaction effect of light treatment with cultivar, the maximum bud length was observed in the Allstar cultivar in LED night day with 4000 lux intensity, which was 20% more than the control. In the Dolcevita cultivar, the maximum bud length was observed in the LED night 4000 lux, which is a 13% increase in bud length compared with the control (Table 5). The bud length index with the indices of bud number, bud diameter, number of leaves, fresh weight, dry weight, and carbohydrate, a positive correlation was observed at the level of 1% and anthocyanin index at the level of 5%, a positive and significant correlation was observed between the traits.

In the interaction effect of light treatment with the cultivar, the largest bud diameter was observed in the Allstar cultivar in LED night 4000 lux treatment, which was 20% more than the control. In the Dolcevita cultivar, the maximum bud length was observed in LED night day 2000 lux, which is an 18% increase in bud diameter compared with the control (Table 5). The bud diameter with indicators of bud length, stem diameter, number of leaves, fresh weight, dry weight, and carbohydrates, a positive correlation was observed at the level of 1% and a positive and significant correlation was observed with the number of buds at the level of 5%.

Kurepin et al. (2010) discovered that long-term cultivation under different light conditions has an effect on internal hormone levels, particularly auxin, and causes homeostasis. Furthermore, it appears that high-intensity blue light destroys or does not produce auxin, altering the auxin-cytokinin ratio. Acetic acid is broken down, resulting in less longitudinal growth and less internode growth (Lee & Palsson, 1994). Alternating red and blue LED light that was on for 8 hours and off for 16 hours increased plant height in lettuce (*Lactuca sativa*) compared to illumination for 4, 2, and 1 hours (Fu et al., 2017).

Table 5. Interaction effect of LED light regimes and rose cultivar on some flower characteristics.

Cultivar	Light (LED day/night) Lux	Bud number	Mean harvest (weekly)	Cut flower height (cm)	Bud length (mm)	Bud diameter (mm)	Number of leaves	Stem diameter (mm)
	Control	4.25c	1.12ab	41.97e	44.90e	32.16e	7.08c	5.11f
	Night 2000	5.42ab	1.01bc	50.85d	48.10d	38.00bc	8.83b	6.13c
	Night 4000	5.41ab	0.92c	46.62de	50.80cd	38.63bc	9.19b	5.913d
	Day 2000	5.81a	0.94c	55.12cd	52.03c	34.70cd	10.38ab	6.75bc
	Day 4000	5.42ab	1.11ab	51.41d	48.45d	37.16bc	9.73ab	6.32c
Allstar	Night Day 2000	5.66ab	0.92c	58.42bcd	51.29c	35.16bcd	9.43b	6.68bc
	Night Day 4000	5.30bc	0.93c	55.19cd	53.83c	36.33bc	9.50b	6.27c
	Dark 2000	3.16d	1.29a	60.71ab	44.86e	34.03cd	8.63b	5.62e
	Dark 4000	3.08d	1.03bc	53.69cd	42.23e	32.06e	8.04bc	4.96g
	Control	4.47c	0.68d	47.21de	52.20c	34.91cd	9.75ab	5.68e
	Night 2000	5.21bc	1.04bc	66.28a	56.66b	39.63bc	12.40a	7.06ab
	Night 4000	6.36a	1.03bc	56.56cd	58.93a	40.00ab	11.90a	7.05ab
	Day 2000	5.70ab	1.13ab	54.00cd	57.23ab	40.00ab	10.71ab	6.91ab
	Day 4000	5.90a	1.44a	58.63bcd	55.70b	41.16a	10.83ab	6.88ab
Dolcevita	Night Day 2000	5.48ab	1.25ab	59.47abc	55.53b	41.30a	12.07a	6.90ab
	Night Day 4000	5.51ab	1.00bc	59.22abc	58.90a	40.73ab	12.03a	7.62a
	Dark 2000	2.33e	1.03bc	63.38ab	49.95d	38.84bc	7.83c	5.12f
	Dark 4000	2.03e	1.23ab	51.76d	43.80e	33.70c	8.39b	5.05f

In each column, the averages that have at least one letter in common do not have a significant difference at the 5% probability level based on the least significant difference (LSD) test.

Alsanius et al, (2017) reported that red LED light 80% + blue 20% with 16 hours of illumination and intensity of 7000 lux increased the plant height and stem diameter of common sunflower, which is consistent with the present study. The effect of red-blue LED light at a ratio of 1:1 with an intensity of 17,000 lux on tomato (*Solanum lycopersicum*) increased the diameter of the plant stem and the height and growth of the root (Li et al., 2017; Alsanius et al., 2017).

Number of leaves, stem diameter, flower quality, greenness index, and chlorophyll fluorescence

In the interaction effect of light treatment with cultivar, the highest number of leaves was observed in the Allstar cultivar in LED day 2000 lux treatment, which was 47% more than the control, and in the Dolcevita cultivar in LED night 2000 lux treatment, which was 27% more than the control (Table 5).

In the interaction effect of light treatment with the cultivar, the maximum stem diameter was observed in the Allstar cultivar in LED day 2000 lux treatment, which was 34% compared with control. In the Dolcevita cultivar, the maximum stem diameter was observed in LED night day 4000 lux, which is a 35% increase in the stem diameter compared to the control, (Table 5). The stem diameter index with the indicators of the number of buds, length of buds, length of buds, number of leaves, quality of flowers, fresh weight, dry weight, and carbohydrates, a positive correlation was observed at the level of 1%, and a positive correlation was observed with the index after harvest at the level of 5%.

In the interaction effect of light treatment with cultivar, the highest flower quality was observed in the Allstar cultivar in LED day 4000 lux, which was 24% compared with control. The highest flower quality was observed in the Dolcevita cultivar in night 400 lux intensity, which was a 22% increase in flower quality compared with the control (Table 6). The flower quality with the parameters of bud number, bud length, bud diameter, stem diameter, number of leaves, fresh weight, dry weight, carbohydrate, and total chlorophyll, it is significant correlation at 1% level and the vase life index is significant at 5% level.

In the interaction effect of light treatment with the cultivar, the highest greenness was observed in the Allstar cultivar in LED night day 2000 lux, which showed a 10% increase in greenness compared with the control (Table 6). The greenness index has a positive correlation with the number of buds at the level of 1%, and a significant positive correlation was observed with anthocyanin and after harvest at the level of 5%.

In the interaction effect of light treatment with cultivar, the highest chlorophyll fluorescence was observed in the Allstar cultivar in LED day 4000 lux intensity, which was 7% compared with control. The highest chlorophyll fluorescence index of 4000 lux was observed in the Dolcevita cultivar at daylight (Table 6). The chlorophyll fluorescence index with weekly harvest, chlorophyll a, and total chlorophyll had a positive and significant correlation, and a negative correlation with thrips was observed at the 1% level.

According to Schroeter-Zakrzewska and Pradita's (2021) experiment, leaf color plays a crucial role in the quality of ornamental plants. They showed that light color significantly affected the SPAD index value in Chrysanthemum plants. Specifically, exposure to white + blue light and white and blue lights resulted in an increase in the SPAD index value. However, red + blue light exposure resulted in the highest index of greening leaves (SPAD) value and the shortest cuttings with the longest roots.

Fresh weight, dry weight, leaf surface, thrips pest symptom

In the interaction effect of light treatment with cultivar, the highest fresh weight of cut flowers was observed in the Allstar cultivar in LED night 4000 lux treatment, which was 43% more than the control. In the Dolcevita cultivar, the heaviest fresh weight of cut flowers was observed in LED night day 4000 lux, which is a 33% increase compared with control (Table 6). A positive correlation was observed with the indices of the number of buds, bud length, stem diameter, dry weight, and carbohydrate at the level of 1% and with the indices of vase life, thrips pest at the level of 5%.

In the interaction effect of light treatment with cultivar, the highest dry weight of cut flowers was observed in the Allstar cultivar in LED night 4000 lux treatment, which was 39% compared with control. The highest dry weight of cut flowers was observed in the Dolcevita cultivar in LED night day 4000 lux intensity, which is a 33% increase compared with control (Table 6). A positive correlation of 1% was observed in dry weight with weekly harvest indices, bud length, bud diameter, stem diameter, number of leaves, fresh weight, and carbohydrate. This finding is consistent with the findings of Fan et al. (2013), who investigated the effect of different intensities of LED light (50 % blue and 50 % red) on tomato (*Solanum lycopersicum*). Schroeter-Zakrzewska and Pradita's (2021) study found that Chrysanthemum plants exposed to white + blue light had the highest fresh and dry weights, averaging about 65.2 and 38.1 g, respectively. In contrast, the plants exposed to red + blue light had the lowest fresh weight (46.9 g) and dry weight (26.3 g).

In the interaction effect of light treatment with the cultivar, the highest leaf surface was observed in the Allstar cultivar in LED night day 2000 lux, and in the Dolcevita cultivar, the highest leaf surface was observed in LED day 2000 lux intensity (Table 6). The leaf surface has no significant correlation with other indicators.

Table 6. Interaction effect of LED light regimes and rose cultivar on some flower characteristics.

Cultivar	Light	Flower quality	Greenness (SPAD)	Chlorophyll fluorescence (Fv/Fm)	F.W. of cut flowers (g)	D. W. of cut flowers (g)	Leaf surface (mm^2)	Thrips pest	Chlorophyll a of leaves (mg/g FW)
Allstar	Control	6.88bc	52.75ab	0.72c	5.63e	33.22bc	6723.60d	8.00a	0.27cde
	Night 2000	7.76ab	51.26ab	0.76ab	6.60c	37.75bc	10499.90bdc	5.66b	0.28cd
	Night 4000	7.77ab	52.30ab	0.75ab	8.03ab	46.21a	8779.30cde	5.33bc	0.31bc
	Day 2000	8.53a	54.23ab	0.77a	7.84ab	43.73abc	12148.80ab	4.66de	0.35b
	Day 4000	8.00a	53.70ab	0.77a	7.47bc	41.23abc	12146.60ab	5.00cd	0.45a
	Night Day 2000	7.99ab	58.10a	0.77a	7.56bc	43.42abc	13317.80a	5.66b	0.22e
	Night Day 4000	8.16a	53.33ab	0.77a	7.61bc	44.52abc	11865.50abc	5.00cd	0.36b
	Dark 2000	7.61ab	48.63bc	0.74b	3.80f	22.92c	9353.60cde	1.66e	0.23e
	Dark 4000	6.13b	51.22ab	0.74b	3.99f	23.04c	11416.30abc	2.00e	0.29cd
Dolcevita	Control	7.10c	50.33ab	0.75ab	6.47c	39.51bc	9925.00cde	8.00a	0.26de
	Night 2000	8.48a	50.50ab	0.77a	8.42b	48.52a	12345.70ab	5.00cd	0.23e
	Night 4000	8.70a	49.36bc	0.75ab	7.84ab	44.91abc	12124.20ab	5.66b	0.31bc
	Day 2000	8.23a	48.96bc	0.77a	8.10ab	45.12abc	13040.20a	4.00de	0.24e
	Day 4000	8.34a	50.13ab	0.77a	7.60bc	44.22abc	11613.50abc	5.33bc	0.32bc
	Night Day 2000	8.13a	48.53bc	0.77a	7.91ab	44.87bac	12225.40ab	5.51b	0.38ab
	Night Day 4000	8.35a	49.43bc	0.77a	8/60a	48.44a	12227.80ab	2.33e	0.38ab
	Dark 2000	6.39bc	47.26b	0.75ab	6.23c	37.35bc	10577.90bcd	2.00e	0.22e
	Dark 4000	6.63bc	39.90c	0.74b	5.70e	31.49bc	14024.00a	8.00a	0.30bc

In each column, the averages that have at least one letter in common do not have a significant difference at the 5% probability level based on the least significant difference (LSD) test. F.W.: Fresh weight; D.W.: Dry weight.

The number of leaves in the LED light regimes and light intensity both increased the number of leaves in the rose. This finding is consistent with Duong et al. (2000) that reported that using LED light 70% red + 30% blue with an intensity of 2600 lux in conjunction with sunlight on strawberry plants can increase the number of leaves, stem and root height, and dry weight compared to plants grown under fluorescent light. Naznin et al. (2019) found that in pepper, leaf number was significantly increased under 95% red light with 5% blue LED compared to 100% red LED.

The plant weight of mint (*Mentha sativa*) and basil (*Ocimum basilicum*) increased at LED light 70% red and 30% blue with 18 hours of lighting 4 times (Sabzalian et al. 2014). Tomatoes were grown under 1:1 blue and red LED light conditions, and the specific leaf surface area and total chlorophyll increased, resulting in better light absorption (Fan et al. 2013).

In the interaction effect of light treatment with cultivar, the highest thrips pest was observed in the control with an average of 8 out of 10 and the lowest thrips drop was observed in LED dark 2000 lux intensity with an average of 1.66. In the Delsovita cultivar, the highest thrips infestation was observed in control and the lowest thrips drop was observed in LED dark 2000 lux (Table 6). There was a positive correlation between the thrips pest index and the number of buds at the 1% level, and a negative correlation was observed with the number of flowers and chlorophyll fluorescence at the 1% level, and a significant corroletion observed with the greenness index, fresh weight, and dry weight.

Johansen et al., (2018) evaluated the phototactic response of *F. occidentalis* to yellow and blue sticky traps with blue LED in colored and white Alstroemeria varieties. They found that catches in blue traps with LED were 3.4 and 4.0 times higher compared to blue traps without LED. In contrast, catches in yellow traps with LED increased by 4.5 times compared to yellow traps without LED, but they were only slightly higher than those observed in blue traps without light and lower than catches in blue traps with LED. This difference is likely due to the reflection of blue light in the blue sticky traps, which produced a higher stimulus, while the blue light is mostly absorbed in the yellow traps.

Physiological factors chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, petal anthocyanin content

In the interaction effect of light treatment with cultivar, the highest chlorophyll a was observed in the Allstar cultivar in LED day 4000 lux, which was 66% compared with control. Delsovita cultivar in LED night day 2000 lux, which is a 46% increase compared with control (Table 6). The chlorophyll a with chlorophyll b, total chlorophyll, and carotenoid indices is significant at 1% level and with life after harvest at 5% level.

In the interaction effect of light treatment with cultivar, the highest chlorophyll b was observed in the Allstar cultivar in LED day 4000 lux, which was 60% compared with the control. The most chlorophyll b was observed in the Delsovita cultivar in LED night day 4000 lux, which is a 42% increase compared to the control (Table 7). The chlorophyll b with total chlorophyll, carotenoids, and after harvest, a positive correlation was observed at the level of 1%, and with the number of leaves and water content, a positive correlation was observed at the level of 5%.

In the interaction effect of light treatment with the cultivar, the highest total chlorophyll was observed in the Allstar cultivar in LED day 4000 lux, which was 63% compared with control. The highest total chlorophyll was observed in the Dolcevita cultivar in LED night day 4000 lux, which is a 44% increase compared to the control (Table 7). The total chlorophyll with carotenoid indicators and after harvesting, a positive correlation was observed at the level of 1%, and with the content of flower water, carbohydrates, and total chlorophyll, a positive correlation was observed at the level of 5%.

In the interaction effect of light treatment with cultivar, the most carotenoid was observed in the Allstar cultivar in LED day 4000 lux, which was 64% compared with control. The most carotenoids were observed in the Dolcevita cultivar in LED night day 2000 lux, which is a 62% increase compared to the control (Table 7). A positive correlation was observed between carotenoids and total chlorophyll indices after harvest, at the level of 1%, and a positive correlation was observed with the content of flower water content and carbohydrates at the level of 5%.

In the interaction effect of light treatment with cultivar, the highest anthocyanin content was observed in the Allstar cultivar in LED day 2000 lux, which was 41% higher than the control. The highest anthocyanin content was observed in the Delsovita cultivar in LED night 2000 lux, which was a 113% increase compared with control (Table 7). The anthocyanin with greenness index at the level of 1% and with the vase life index, carbohydrate, and flower water content, a positive correlation was observed at the level of 5%.

Chlorophylls try to adapt to the environment in different environmental conditions so that the chlorophyll content changes to improve maximum photon absorption in different environmental conditions (Samuoliene et al., 2011). When a plant is exposed to blue light in addition to other wavelengths, its chlorophyll content increases (Hernandez, 2013). According to Wu et al. (2007), pigments, particularly chlorophyll and carotenoid, decreases in the dark. The duration of light exposure can also affect the chlorophyll content. However, it has been determined that red light causes carotenoid and anthocyanin accumulation while blue light causes chlorophyll accumulation. Anthocyanin biosynthesis is typically linked to blue light via cryptochromes. However, active phytochrome is required for the regulation of anthocyanin synthesis via cryptochromes, and this requirement can be related to the presence of phytochrome an or phytochrome b (Ahmad & Cashmore, 1997).

According to Zhang et al. (2020), increasing the exposure time to light results in an increase in chlorophyll and carotenoids in microgreens, which is consistent with the current study. Fan et al. (2013) found that exposing cabbage to a red-blue LED light with a 6:1 ratio of 8000 lux without sunlight for 12 hours on and 12 hours off increased carotenoids by about 70% when compared to mono spectral lights.

The effect of LED and cultivar on the vase life of two rose cultivars

Soluble carbohydrate, vase life parameters, and the speed of flower bud opening

In the interaction effect of light treatment with cultivar, the highest carbohydrate was observed in the Allstar cultivar in LED day 4000 lux, which was 31% compared with control. In the Dolcevita cultivar, the highest carbohydrates were observed in LED night day 4000 lux, which is a 142% increase compared with control (Table 7). The carbohydrate content has a positive correlation with the number of buds, bud length, bud diameter, stem diameter, number of leaves, flower quality, fresh weight, and dry weight at the level of 1%, and with chlorophyll and water content, there is a positive and significant correlation at the level of 5% was observed.

Growing tomatoes under 70% red + 30% blue light without sunlight with a light intensity of 15,000 lux was shown by Li et al. (2017) to increase total carbohydrates and starch, as well as sucrose accumulation. Hao et al. (2016) found that red-blue supplementary LED light at a ratio of 1:1 with an intensity of 4700 lux increased the number of flower buds as well as the amount of carbohydrates, which is consistent with the current study.

In the interaction effect of light treatment with cultivar, the longest vase life was observed in the Allstar cultivar in LED night day 4000 lux, which is 44% compared with control. In the

Dolcevita cultivar, the longest vase life was observed in LED day 4000 lux, which is a 133% increase compared with control (Table 7). The vase life index has a positive correlation with the number of buds, chlorophyll b, total chlorophyll, carotenoids, and anthocyanins at the 1% level, as well as with stem diameter, flower quality, greenness, fresh weight, dry weight, flower water content, chlorophyll A positive correlation was observed at the 5% level.

Horticultural products have a limited shelf life after harvesting, which is due to factors such as weight loss, aging, loss of strength, softening of tissue corruption, and so on. Supplemental lighting during plant growth can increase vase life by assisting in the storage of sugars and carbohydrates (Hasperue et al., 2016). The use of LED light has a significant impact on the life of horticultural products after harvest. In its most basic form, artificial LED lights can help with more photosynthesis assimilate and more food storage (Dayani et al., 2018). According to Samuoliene et al. (2012), in a study of the effect of red LED light on the changes in photochemical content in lettuce leaves, it was discovered that exposing lettuce plants to LED light during cultivation increased the production of ascorbic acid, which has antioxidant properties and reduces the activity of radicals. In the same study, the carbohydrate content and antioxidant capacity of the lettuce plant increased under the LED light treatment, which had a positive correlation with the increase in vase life after harvesting the plant (Samuoliene et al., 2012).

A study found that using a 1000 lux LED supplemental light increased the vase life of cabbage after harvesting and delayed the yellowing of its inflorescences (Hasperue et al., 2016). It was able to increase the vase life of the plant after harvesting by 30% more than the Allstar control and 23% more than the Dolsovita control in the vase life light intensity index of 4000 lux, which is consistent with the research of Pettersen et al. (2007) who reported that increasing the exposure time to the plant increased the longevity of flowers on potted roses.

Table 7. Interaction effect of LED light regimes and rose cultivar on some flower characteristics.

Cultivar	Light	Chlorophyll b of leaves (mg/g FW)	Total Chlorophyll of leaves (mg/g FW)	Carotenoids of leaves (mg/g FW)	Anthocyanin of petal (µmol/g)	Carbohydrate of leaves (mg/g)	Vase life (day)	Speed of flower bud opening (mm/day)	Flower water content (%)
	Control	0.20e	0.73bc	0.17cde	227.68bcd	124.05de	9.00de	2.021c	81.21b
	Night 2000	0.21de	0.77bc	0.18cde	283.84ab	148.00d	11.00c	2.22bc	82.90ab
	Night 4000	0.25ab	0.87b	0.20bc	310.81a	160.50a	11.66c	2.29bc	82.73ab
	Day 2000	0.24bc	0.93b	0.23b	322.73a	152.69d	12.33b	2.73a	83.24a
	Day 4000	0.32a	1.19a	0.28a	307.58a	163.23cd	12.33b	2.82a	82.65ab
Allstar	Night Day 2000	0.19efg	0.73bc	0.15e	258.29abc	159.25d	11.66c	2.82a	83.11a
	Night Day 4000	0.29a	0.99b	0.23b	258.89abc	157.30d	13.00a	2.76a	82.45ab
	Dark 2000	0.20e	0.65d	0.15e	163.43de	125.706de	10.00d	2.16c	81.84b
	Dark 4000	0.22cd	0.78bc	0.19cd	194.75cd	129.75de	9.66de	2.73a	82.00ab
	Control	0.19efg	0.70cd	0.16e	13.99g	74.14f	5.00e	1.79f	82.02ab
	Night 2000	0.21de	0.66d	0.14e	29.83g	155.40d	10.00d	2.61abc	83.38a
	Night 4000	0.22cd	0.83b	0.19cd	21.21g	168.18abc	11.33c	2.27bc	83.17a
Dolcevita	Day 2000	0.17g	0.64d	0.15e	19.80g	163.37cd	11.66c	2.87a	83.40a
	Day 4000	0.24bc	0.87b	0.21bc	24.34g	176.30ab	11.66c	2.64abc	83.46a
	Night Day 2000	0.26ab	1.01a	0.26a	17.37g	167.19bc	10.66d	2.94a	83.11a
	Night Day 4000	0.27a	1.01a	0.25a	22.32g	179.84a	8.33de	2.59bcd	83.49a
	Dark 2000	0.19efg	0.63d	0.13e	11.52g	138.91d	10.00d	3.00a	82.60ab
	Dark 4000	0.21de	0.79bc	0.18cde	12.13g	147.63d	11.33c	2.05ef	82.30ab

In each column, the averages that have at least one letter in common do not have a significant difference at the 5% probability level based on the least significant difference (LSD) test.

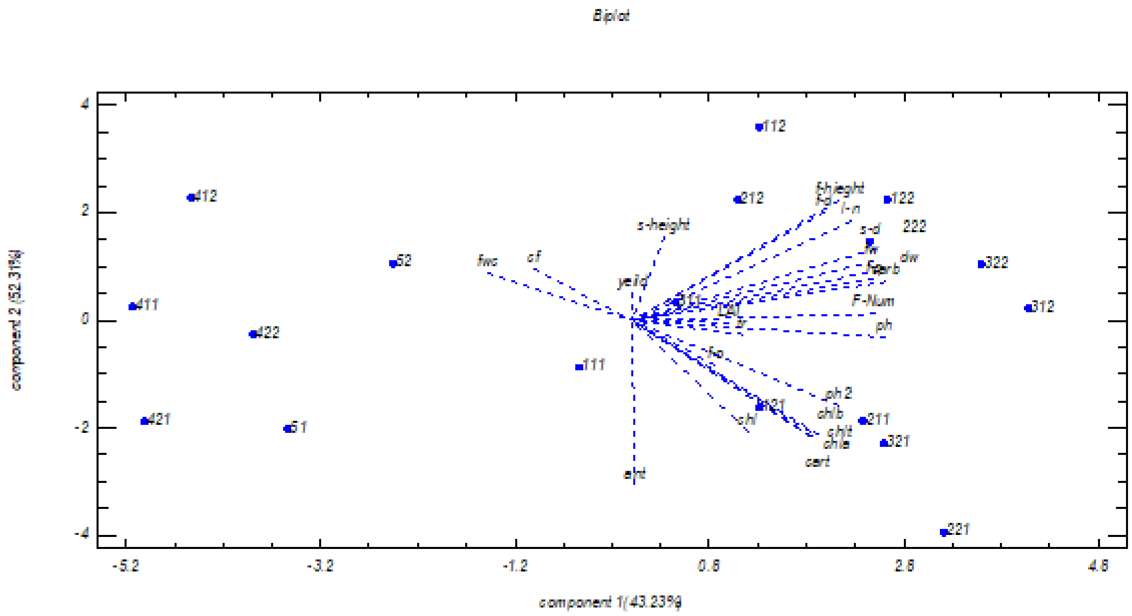

Fig. 3. The PCA analysis of the effect of LED on some characteristics of Rose.
Bud number (F-Nun), Mean harvest weekly (yield), Cut flower height (S-height), Bud diameter (F-d), Stem diameter (S-d), Number of leaves (l-n), Flower quality (f-q), Greenness (Chl), Chlorophyll fluorescence (cf), Fresh weight (fw), Dry weight (dw), Flower water content (fwc), Vase life 1 day (ph), Vase life 2 day (ph2), Chlorophyll a (Chla), Chlorophyll b (Chlb), Total chlorophyll (Chlt), Carotenoid (Cart), Anthocyanin (ant), Leaf surface (LA1), Thrips pest (tr), Speed of flower bud opening (f-o), Carbohydrate of leaves (Carb). N2 Allstar (111), N4 Allstar (121), D2 Allstar (211), D4 Allstar (221), DN2 Allstar (311), DN4 Allstar (321), T2 Allstar (411), T4 Allstar (421), Control1 Allstar (51), N2 Dolcevita (112), N4 Dolcevita (122), D2 Dolcevita (212), D4 Dolcevita (222), ND2 Dolcevita (312), ND4 Dolcevita (322), T2 Dolcevita (412), T4 Dolcevita (422), Control 11 Dolcevita (52).

In the interaction effect of light treatment with the cultivar, the Allstar cultivar had the fastest flower opening in LED day 4000 lux, which was 40% faster than the control (Table 7).

Flower water content was highest in LED day 2000 lux in Allstar and in night day 4000 lux in Dolcevita cultivar (Table 7).

According to PCA the best light intensity for increasing growth parameters and pigment content with 4000 lux in both cultivars and the best LED regime was 24 hours on (with sunlight), 24 hours light (without sunlight) in both cultivars improve the majority of flowers characteristics (Fig. 3).

CONCLUSION

Conclusively, chlorophyll parameters such as chlorophyll a, b, total, carotenoid, chlorophyll fluorescence and also the average number of flower harvests per week improved in LED day 4000 lux. The light intensity of 4000 lux had a better effect on the vase life of roses in both cultivars. Allstar showed the longest vase life in the treatment of LED night day 4000 lux, and Dolcevita showed the longest vase life in LED day 4000 lux treatment. In general, according to the information obtained in this research, it is recommended to use 4000 lux LED supplemental light during the day to increase the quantity and quality of roses in low light seasons (autumn and winter).

Conflict of interest

To the best of our knowledge, the named authors have no conflict of interest, financial or otherwise.

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