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RESEARCH ARTICLE

Manipulating Light Duration and Intensity Using LEDs to Enhance Off-Season Yield of *Hylocereus polyrhizus* in a Tropical Area of Banyuwangi, East Java, Indonesia

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Abstract: This study aimed to examine the effect of light duration and Light Emitting Diode (LED) power on the production of red dragon fruit during the off-season. The experiment was conducted in Bulurejo, Banyuwangi, East Java, Indonesia, from March to June 2024 using a split-plot design. The main plot consisted of LED illumination duration (2, 4, and 6 hours), while the subplot consisted of LED power levels (6, 9, 12, and 15 watts). Observations included environmental parameters (temperature, humidity, and heat units), plant phenology (number of flowers and fruits), and fruit quality attributes (fruit weight, volume, sugar content, and anthocyanin content). Data were analyzed using analysis of variance (ANOVA) followed by appropriate mean comparison tests. The results showed a significant interaction between illumination duration and LED power on the number of flowers. Treatments of 4 hours (P2) and 6 hours (P3) illumination were able to significantly increase the number of fruits, while the use of 12-watt LED (D3) produced the highest results for number of fruits, fruit weight, and sugar content. The increase in light intensity proved to enhance photosynthesis, sugar accumulation, and fruit quality, although anthocyanin accumulation tended to decrease along with increasing productivity. Thus, the combination of 4–6 hours of illumination with 12-watt LED was the most optimal treatment to improve the productivity and quality of red dragon fruit during the off-season. This study demonstrates that optimizing both light duration and intensity can effectively enhance off-season productivity and fruit quality of red dragon fruit, providing a practical lighting strategy for tropical cultivation systems.

Keywords: Hylocereus Polyrhizus, LED, Photoperiodism, Off-Season, Antioxidant

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Introduction

Indonesia is a tropical country with great potential for the development of horticultural commodities, including dragon fruit (Hylocereus spp.). Red dragon fruit has become a leading commodity in Banyuwangi Regency, which is recognized as a national production center. Dragon fruit possesses high economic value and is in great demand in both domestic and international markets. However, dragon fruit production still faces a major constraint, namely its seasonal fruiting pattern [1, 2].

Agronomically, the flowering and fruiting cycle of dragon fruit in Banyuwangi occurs from October to March, while during the period from April to September the plants neither flower nor bear fruit. This causes fluctuations in supply and instability of dragon fruit availability in the market [3]. Therefore, cultivation strategies capable of inducing off-season flowering are required to increase productivity and maintain supply continuity.

Physiologically, light plays an important role in photosynthesis, respiration, hormone regulation, and the process of flowering induction. Three aspects of light that affect plant growth are photoperiodism, intensity, and light quality. Dragon fruit is classified as a long-day plant that requires illumination of more than 12 hours to induce flowering. The addition of artificial light during the night has been proven effective in extending the photoperiod and stimulating flowering [4].

Several studies have reported that extending illumination for 6 hours at night gives the best results for increasing off-season dragon fruit production [5]. This manipulation of photoperiodism can enhance carbon fixation, improve chlorophyll accumulation, and activate metabolic pathways associated with flower induction [6].

In practice, various types of lamps have been used for supplemental lighting. One technology that has been rapidly developed is the Light Emitting Diode (LED) lamp. Compared with incandescent lamps or Compact Fluorescent Lamps (CFL), LEDs have higher energy efficiency, a light spectrum more suitable for plant growth, longer lifespan, and lower operational costs [7, 8]. From a physiological perspective, LED application can also influence the synthesis of phytohormones such as auxins, gibberellins, and florigen, which play a role in flower development [6]. In addition, lamp power plays an important role in determining the light intensity received by the plant. Power variation affects the microclimatic temperature around the plant and the balance of light energy required for flowering. Insufficient lamp power may reduce the effectiveness of induction, whereas excessive power may increase environmental temperature excessively, thereby disrupting plant physiology [9].

Research on the interaction between illumination duration and LED lamp power is therefore important to determine the optimal combination that can improve the off-season production of red dragon fruit (*Hylocereus polyrhizus*). The results of this study are expected to contribute to the development of agronomic and physiological science, as well as provide a basis for sustainable cultivation technology to support the continuity of dragon fruit supply in the market.

Methods

Research Location

The research was conducted in Bulurejo Village, Purwoharjo Subdistrict, Banyuwangi Regency, East Java Province, Indonesia, located approximately at the geographical coordinates of 8 28′ 19.4″ S and 114 11′ 45.3″ E. (±100 m above sea level) on March to June 2024. The research site has latosol soil type, an average rainfall of 153.5 mm per month, an average temperature of 27°C, and a relative humidity of 80%. The research was carried out from March to Juni 2024.

Materials and Tools

The research materials included five-year-old red dragon fruit plants (*Hylocereus polyrhizus* var. Red Rose), yellow LED lamps with power of 6, 9, 12, and 15 watts, NPK fertilizer (20 g/plant/month), and electrical cables. The tools used were a digital thermometer, hygrometer, digital balance, refractometer, and lux meter.

Experimental Design

The study used a Split-Plot Design with two factors:

Main plot: LED illumination duration (2 hours (P1), 4 hours (P2), and 6 hours (P3))

Subplot: LED power (6 watts (D1), 9 watts (D2), 12 watts (D3), and 15 watts (D4))

The combination of treatments totaled 12 with three replications. Each replication consisted of three poles of plants, with each pole containing three plants, resulting in nine plants per treatment. A total of 324 plants were observed as research samples.

Research Procedure

The plants used in this study were selected based on uniformity and health conditions. Only healthy plants free from pests and diseases were included. The selected plants had relatively similar canopy height and width to ensure uniform growth conditions. All experimental plants were of the same age, approximately 5 years old.

LED lamps were installed at a height of 30 cm above the plant canopy, with one lamp assigned to every two plant poles. The experimental treatments were arranged according to a split-plot design, where LED illumination duration (2, 4, and 6 hours) was applied as the main plot, and LED power (6, 9, 12, and 15 watts) as the subplot. The illumination treatments were applied daily during the night period according to the designated duration for each treatment.

Prior to treatment application, uniform and healthy plants were selected to ensure consistent growth conditions. Routine plant maintenance was carried out throughout the experimental period, including the application of NPK fertilizer at a rate of 20 g per plant per month. Irrigation was conducted once every 7 days or adjusted based on soil moisture conditions. Weed control was performed manually, while pest and disease management was carried out as needed based on field observations using appropriate control measures.

Observed Variables

The observed variables included: Environment: temperature change (°C), relative humidity (%). Plant phenology: number of flowers and number of harvested fruits per plant.

Fruit characteristics included average fruit weight (g), fruit volume (ml), total sugar content (°Brix), and anthocyanin content (%). Anthocyanin content (%) was determined following the AOAC Official Method 2002.02 as described by AOAC International (2005). The anthocyanin analysis of dragon fruit was conducted at the Food Technology Laboratory, Politeknik Negeri Jember.

Data Analysis

Data were analyzed using analysis of variance (ANOVA) with the assistance of SmartStatXL software. If significant effects were observed, further testing was conducted using the Least Significant Difference (LSD) test at the 5% and 1% levels to differentiate treatments more specifically [10].

Results

Observation of the time of first flower emergence (Table 1) showed that there was an effect of illumination duration and LED power. The results can be explained by the interaction that occurred in the number of flowers due to the treatments of LED illumination duration and LED power.

Table 1: Effect of Illumination Duration and LED Power on the Time of First Flower Emergence of Red Dragon Fruit Plants

Illumination duration (P)	**Time of first flower emergence (DAE)**
P1	14.42 b
P2	13.33 ab
P3	12.08 a
LSD 5% P	1.41
LED power (D)	Time of first flower emergence (DAE)
D1	14.00 b
D2	13.89 b
D3	12.11 a
D4	13.11 ab
LSD 5% D	1.09

Notes: Numbers followed by the same letter in the same column are not significantly different according to the LSD test at the 5% level; DAE: days after exposure; P1 = illumination duration of 2 hours (17:00–19:00); P2 = illumination duration of 4 hours (17:00–21:00); P3 = illumination duration of 6 hours (17:00–23:00); D1 = LED power 6 watts; D2 = LED power 9 watts; D3 = LED power 12 watts; D4 = LED power 15 watts

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Based on the results of the study, the number of fruits produced from the 4-hour illumination treatment (P2) and the 6-hour illumination treatment (P3) did not differ significantly, whereas the use of 12-watt LED power (D3) resulted in the highest number of fruits compared to the other treatments (Figure 1), The treatment with 12-watt LED power (D3) produced the highest fruit weight, while the treatment with 15-watt LED power (D4) resulted in the greatest peel thickness compared to the other treatments . The results indicate that the use of LED power can influence the fruit weight and peel thickness of dragon fruit (Figure 2). The sugar content in dragon fruit indicates the level of sweetness of the fruit (Figure 3). The results of the study showed that the treatment with 6 hours of illumination (P3) produced higher values compared to other treatments, while the treatment using LED power of 12 watts (D3) obtained the highest sugar content.

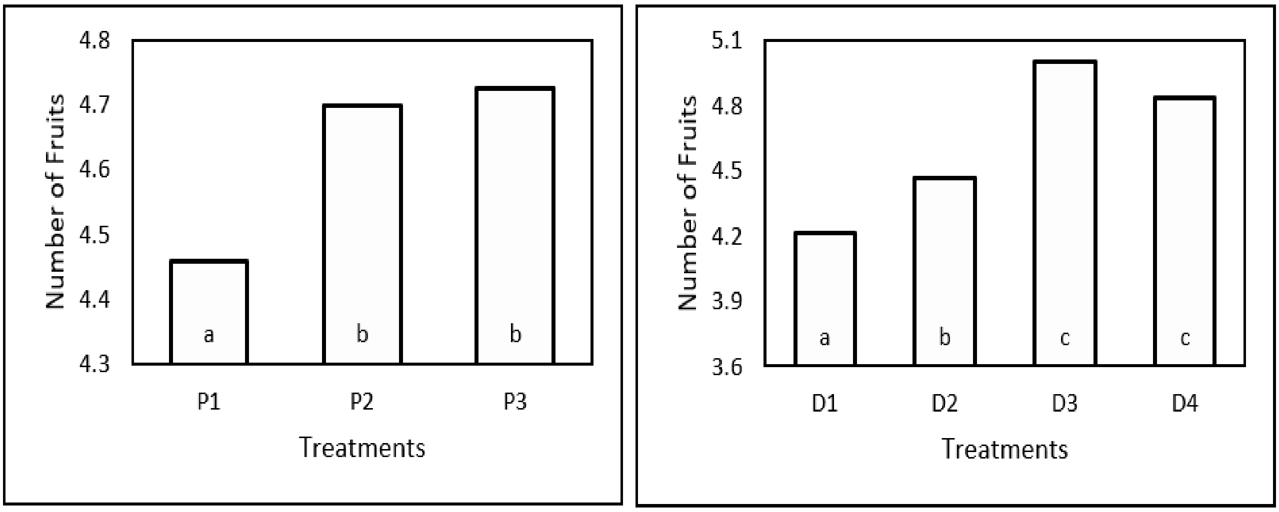

Fig. 1: Bar Diagram of Illumination Duration and LED Power on the Number of Red Dragon Fruit per Plant

Note: P1 = illumination duration 2 hours (17:00–19:00); P2 = illumination duration 4 hours (17:00–21:00); P3 = illumination duration 6 hours (17:00–23:00); D1 = LED power 6 watts; D2 = LED power 9 watts; D3 = LED power 12 watts; D4 = LED power 15 watts

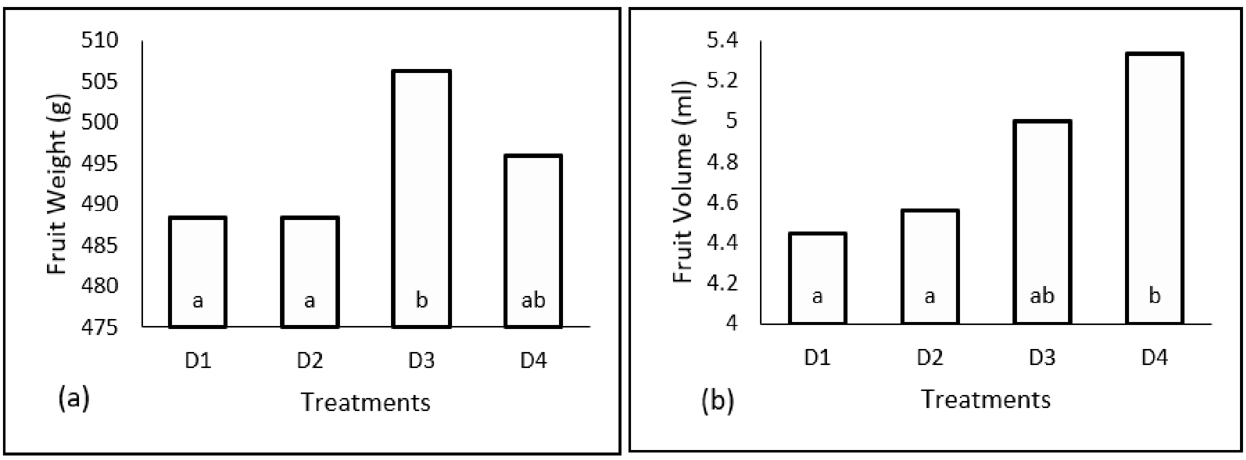

Fig. 2: a. Effect of Illumination Duration on Dragon Fruit Weight; b. Effect of LED Power on Dragon Fruit Peel Thickness

Note: D1 = LED power 6 watts; D2 = LED power 9 watts; D3 = LED power 12 watts; D4 = LED power 15 watts

One of the observations for fruit freshness was carried out on the color of dragon fruit (Table 2). Freshness of the fruit was observed qualitatively using the Munsell color chart, which shows three color components: hue, value, and chroma. Based on the research results, several colors of fruit were found, namely strong purplish red 63A, strong purplish red 60B, strong purplish red 61B, moderate purplish red 59C, and deep red 60D.

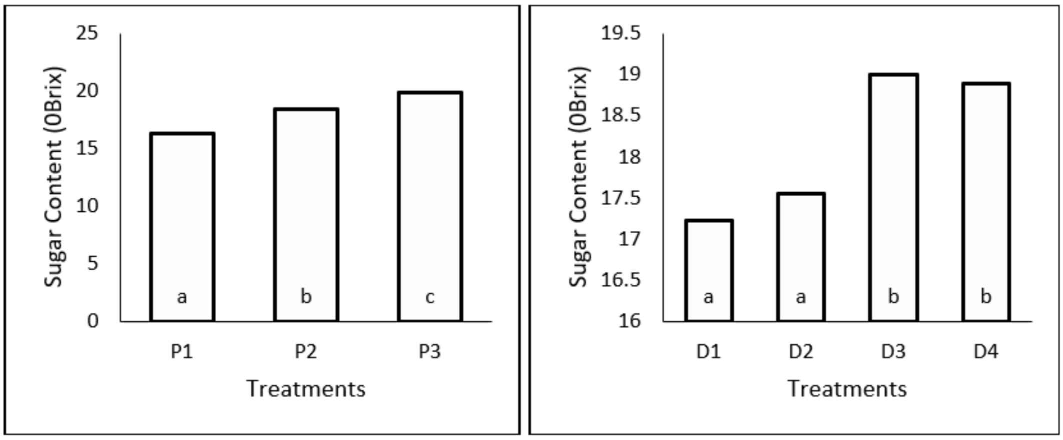

Fig. 3: Effect of Illumination Duration and LED Power on Sugar Content (0Brix) of Dragon Fruit Plants

Note: P1 = illumination duration 2 hours (17:00 – 19:00); P2 = illumination duration 4 hours (17:00 – 21:00); P3 = illumination duration 6 hours (17:00 – 23:00); D1 = LED power 6 watts; D2 = LED power 9 watts; D3 = LED power 12 watts; D4 = LED power 15 watts

Table 2: Effect of Illumination Duration and LED Power on Fruit Color and Anthocyanin Content of Dragon Fruit

Treatments	Color	Anthocyanin (mg/100gr)
P1D1	Strong purplish red 63A	83.17 ± 0.06
P1D2	Strong purplish red 60B	83.46 ± 0.12
P1D3	Strong purplish red 61B	83.27 ± 0.04
P1D4	Moderate purplish red 59C	83.49 ± 0.11
P2D1	Strong purplish red 61B	79.45 ± 0.17
P2D2	Deep red 60D	79.65 ± 0.07
P2D3	Moderate purplish red 59C	79.31 ± 0.08
P2D4	Moderate purplish red 59C	79.54 ± 0.06
P3D1	Strong purlish red 63A	81.74 ± 0.04
P3D2	Moderate purplish red 59C	81.53 ± 0.04
P3D3	Strong purlish red 63A	81.86 ± 0.08
P3D4	Strong purlish red 61B	81.48 ± 0.08

Discussion

Figure 4 shows the response of the number of dragon fruit flowers, where at P1 the regression equation was obtained as y = -0,0075x2+0,2905x +2,4635 and R^2 = 0,9732, at P2 the equation was y = -0,0206x2 + 0,5023x +2,023 and R^2 = 0,9995 and at P3 the equation was y = -0,0083x2+0,2917x +2,895 and R^2 = 0,6702, this means that increasing LED power and illumination duration was able to increase the number of dragon fruit flowers.

Light intensity during growth up to the flowering process is required by the plant, as it is related to the light needed for photosynthesis. Flowering may decrease or be delayed if illumination is reduced. The increase in the number of flowers with increasing light intensity is most likely related to the increase in illumination for photosynthesis [11].

Dragon fruit is a long-day plant that requires a day length longer than a certain critical day length (12 hours) in order to flower [12]. Naturally, dragon fruit will produce flowers and fruits only during the long-day months [4]. The flowering period of dragon fruit is influenced by temperature and light, especially light intensity and illumination duration. This is because dragon fruit is a long-day plant in which flower induction is strongly influenced by illumination [13]. The process of flower development into dragon fruit is affected by photosynthesis; if photosynthetic activity decreases, it will affect flower and fruit formation. According to [2], the number of fruits is also related to illumination duration, and dragon fruit plants are unable to flower and fruit during the off-season.

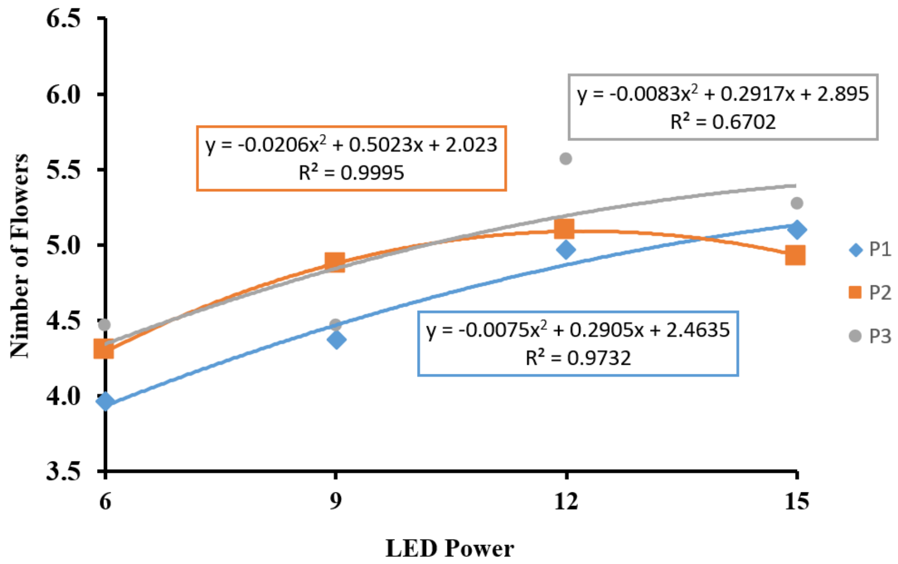

Fig. 4: Regression of Illumination Duration and LED Power on the Number of Flowers of Dragon Fruit Plants

Note: P1 = illumination duration 2 hours (17:00 – 19:00); P2 = illumination duration 4 hours (17:00 – 21:00); P3 = illumination duration 6 hours (17:00 – 23:00)

The application of a 12-watt LED (D3) resulted in the highest fruit weight among all treatments, indicating its effectiveness in promoting fruit growth. In contrast, the 15-watt LED treatment (D4) produced fruits with the greatest peel thickness compared to the other treatments, suggesting that higher light intensity may influence the development of fruit peel characteristics. LED lamps are a type of energy-saving light that can be used as supplemental artificial illumination in plant environments, thereby contributing to increased crop production [14, 15]. Additional lighting to support plant growth can be provided through appropriate artificial light, one of which is the Light-Emitting Diode (LED), as it provides monochromatic light, low emission, and a longer lifespan [16].

The results of the study demonstrated that the 6-hour illumination treatment (P3) consistently produced higher sugar content values compared to all other treatments applied in this experiment. This finding suggests that extending the duration of light exposure plays an important role in enhancing sugar accumulation in the fruit. Furthermore, among the different LED power treatments, the use of a 12-watt LED (D3) resulted in the highest sugar content, indicating that higher light intensity may contribute significantly to the improvement of fruit sweetness. Together, these results highlight the combined effect of illumination duration and light intensity in influencing sugar formation in dragon fruit. The sugar content of dragon fruit serves as an indicator of fruit quality and ripeness. Sugar content is the result of plant photosynthesis stored in the fruit, functioning as a food reserve. Photosynthesis and respiration processes cause changes in the chemical composition of fruits. In general, this is marked by the change in fruit taste from sour to sweet in line with the stages of fruit development. The sweet taste of ripe fruit is a result of starch hydrolysis into simple sugars (glucose). Meanwhile, the sour taste present in young (unripe) fruit is caused by the accumulation of organic acids [17].

The change in dragon fruit peel color is due to the degradation of chlorophyll and the synthesis of betacyanin pigments. These pigments belong to the betalain group. Betalains are found in beetroot, bougainvillea, and most cacti. Betacyanin pigments cause reddish to purple coloration in plant parts such as flower petals, fruits, leaves, stems, and roots. The synthesis of these pigments is assisted by sunlight [18].

Color change in the fruit peel is also caused by a decrease in chlorophyll content and an increase in anthocyanin content. Dragon fruits harvested before reaching full ripeness will undergo a degreening process caused by the decline of chlorophyll content and the increase of betacyanin pigments [19, 20]. Meanwhile, [20] extracted dragon fruit peel (Hylocereus undatus) and found that conditions such as pH, temperature, and light exposure affect anthocyanin stability. Dragon fruit peel contains compounds such as cyanidin-3-O-glucoside, cyanidin-3,5-O-glucoside, and pelargonidin-3,5-O-glucoside [22]. Anthocyanins are more stable at low temperatures (~4°C), acidic pH (~4), and in the absence of light. In addition, the study of [23] showed that the bioactive content in red-fleshed dragon fruit (*Hylocereus polyrhizus*) at various development stages changes as the fruit develops; generally, pigment content increases as ripening approaches.

Table 3: Correlation Matrix of Illumination Duration and LED Power on Dragon Fruit Plants

	AT	TD	FFE	SC	NFr	NF	FW	FV	AC	PT
AT	1.00	1.00 *	-0.45	0.41	0.74 *	0.80 *	0.52	0.66 *	0.05	0.98 *
TD	1.00 *	1.00	-0.45	0.41	0.74 *	0.80 *	0.52	0.66 *	0.05	0.98 *
FFE	-0.45	-0.45	1.00	-0.89 *	-0.78 *	-0.73 *	-0.81 *	-0.57	0.32	-0.45
SC	0.41	0.41	-0.89 *	1.00	0.77 *	0.74 *	0.81 *	0.62 *	-0.47	0.37
NFr	0.74 *	0.74 *	-0.78 *	0.77 *	1.00	0.97 *	0.77 *	0.81 *	-0.27	0.68 *
NF	0.80 *	0.80 *	-0.73 *	0.74 *	0.97 *	1.00	0.76 *	0.85 *	-0.14	0.74 *
FW	0.52	0.52	-0.81 *	0.81 *	0.77 *	0.76 *	1.00	0.79 *	-0.14	0.43
FV	0.66 *	0.66 *	-0.57	0.62 *	0.81 *	0.85 *	0.79 *	1.00	-0.20	0.56
AC	0.05	0.05	0.32	-0.47	-0.27	-0.14	-0.14	-0.20	1.00	0.08
PT	0.98 *	0.98 *	-0.45	0.37	0.68 *	0.74 *	0.43	0.56	0.08	1.00

Notes: AT: Average Temperature; TD: Temperature Difference with Control; FFE: First Flower Emergence; SC: Sugar Content; NFr: Number of Fruits; NF: Number of Flowers; FW: Fruit Weight; FV: Fruit Volume; AC: Anthocyanin Content; PT: Peel Thickness

Based on the results of the correlation analysis (Table 3), average temperature showed a strong positive relationship with several yield parameters of dragon fruit, including number of flowers (r ≈ 0.80), number of fruits (r ≈ 0.74), fruit volume (r ≈ 0.66), and peel thickness (r ≈ 0.98). This indicates that the increase in temperature generated by LED illumination treatments enhanced the physiological activity of the plants, particularly during the generative phase, thereby supporting flower and fruit formation. Temperature rise also contributed to peel thickening, which may be interpreted as an adaptive response of the plants to high light intensity and increased cellular metabolic rates.

Furthermore, fruit sugar content exhibited a positive correlation with several productivity parameters, including fruit weight (r ≈ 0.81), number of fruits (r ≈ 0.77), number of flowers (r ≈ 0.74), and fruit volume (r ≈ 0.62). These findings emphasize the role of sugar accumulation as an important indicator of sink strength, whereby the developing fruit is able to effectively absorb assimilates from photosynthesis to support growth in size and flavor quality. However, sugar content was negatively correlated with anthocyanin levels (r ≈ –0.47), suggesting a trade-off between sweetness improvement and pigment accumulation.

The number of fruits was very strongly correlated with the number of flowers (r ≈ 0.97), as well as with fruit volume (r ≈ 0.81) and fruit weight (r ≈ 0.77). This underscores that successful flowering has a direct implication on enhancing harvest productivity. Conversely, anthocyanin levels showed weak to moderate negative correlations with most yield indicators (–0.14 to –0.47), supporting the notion that increased yield intensity tends to be accompanied by reduced pigment accumulation. This phenomenon is important to consider in cultivation strategies, especially in balancing between production quantity and the visual quality of the fruit.

Several studies on fruit and vegetable crops have reported that a combination of red + blue light or the use of supplemental intra-canopy LEDs can enhance soluble sugar content and fruit growth. For example, in tomato plants, [24] reported that LED supplementation and manipulation of the red-to-blue ratio resulted in increased sugar accumulation and fruit size. Overall, the combination of 4–6 hours of illumination with 12-watt LED lamps was the most optimal treatment and can be recommended as a sustainable cultivation strategy to maintain the continuity of off-season red dragon fruit production.

Conclusion

Light duration and LED wattage significantly affected flowering and off-season productivity of red dragon fruit (Hylocereus polyrhizus). Illumination for 4–6 hours was more effective than 2 hours in increasing the number of flowers and fruits. The 12-watt LED treatment produced the best results in terms of fruit number, fruit weight, and sugar content. Therefore, the appropriate combination of light duration and LED wattage can be used to optimize off-season production of red dragon fruit.

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Author's Contributions

All authors contributed to the study's conceptualization and design, participated in writing the original draft and reviewed and approved the final version of the manuscript.

Ethics

This paper does not involve any human participants and/or animals. Ethical approval is not required and this paper did not perform any experiment or research that requires informed consent.

Conflicts of Interest

The authors have no competing interests to declare relevant to this article's content. The authors also have no relevant financial or non-financial interests to disclose.

References

1. Zahara, F., & Fuadiyah, S. (2021). Pengaruh cahaya matahari terhadap proses fotosintesis. Prosiding Seminar Nasional Biologi (Semnas Biologi FMIPA UNP), 1–4.
2. Izzulhaq, A. J., & Usmadi, U. (2024). Pengaruh Lama Penyinaran Cahaya Led Terhadap Induksi Pembungaan dan Hasil Buah Naga (*Hylocereus Polyrhizus*). Berkala Ilmiah Pertanian, 7(2), 70. https://doi.org/10.19184/bip.v7i2.41188
3. Ayu, N., Pellokila, M. R., Lango, A. N. P., Mahasiswa, J. S., Agribisnis, J., & Pertanian, F. (2023). Determinan Factor of Red Dragon Fruit Production (*Hylocereus polyrhizus*) A Case Study of Desa Kolobolon Kecamatan Lobalain Kabupaten Rote Ndao (Note: Corrected minor typos from the original text: "DRagong" to "Dragon" and "Stsudy" to "Study"). Impas, 24(3), 258–264.
4. Rashid, A. S. M. H., Azam, Md. G., & Chowdhury, S. M. K. H. (2021). Influence of Day-length Enhancement through Night-breaking by Artificial Lighting on Off-season Dragon Fruit Production. Asian Journal of Advances in Agricultural Research, 17(3), 1–10. https://doi.org/10.9734/ajaar/2021/v17i230190
5. Hasibuan, S. (2025). Analysis of Light Intensity from Various Types of Light Bulbs, Distance, and Time on Fruit Plants Dragon Fruit (*Hylocereus Polyrhizus*) in the Generative Phase. Jurnal Penelitian Pendidikan IPA, 11(12), 986–997. https://doi.org/10.29303/jppipa.v11i12.13347
6. Sena, S., Kumari, S., Kumar, V., & Husen, A. (2024). Light emitting diode (LED) lights for the improvement of plant performance and production: A comprehensive review. Current Research in Biotechnology, 7, 100184. https://doi.org/10.1016/j.crbiot.2024.100184
7. Ma, Y., Xu, A., & Cheng, Z.-M. (Max). (2021). Effects of light emitting diode lights on plant growth, development and traits a meta-analysis. Horticultural Plant Journal, 7(6), 552–564. https://doi.org/10.1016/j.hpj.2020.05.007
8. Ahsan, S. M., Injamum-Ul-Hoque, Md., Shaffique, S., Ayoobi, A., Rahman, M. A., Rahman, M. M., & Choi, H. W. (2024). Illuminating Cannabis sativa L.: The Power of Light in Enhancing C. sativa Growth and Secondary Metabolite Production. Plants, 13(19), 2774. https://doi.org/10.3390/plants13192774
9. Al-Qthanin, R. N., & Alshaharni, M. O. (2024). Effect of lighting system on the growth rate of two cultivars of dragon fruit (Hylocereus undatus and Hylocereus costaricensis) in Abha region, Saudi Arabia. Applied Ecology and Environmental Research, 22(3), 2541–2554. https://doi.org/10.15666/aeer/2203_25412554
10. Gomez, K. A., & Gomez, A. A. (1986). Statistical Procedures for Agricultural Research. 22. https://doi.org/10.1017/s0014479700014496
11. Rezazadeh, A., Harkess, R. L., & Telmadarrehei, T. (2018). The Effect of Light Intensity and Temperature on Flowering and Morphology of Potted Red Firespike. Horticulturae, 4(4), 36. https://doi.org/10.3390/horticulturae4040036
12. Tran, D.-H., Yen, Chung-Ruey, & Chen, Y.-K. H. (2015). Flowering response of a red pitaya germplasm collection to lighting addition. International Journal of Agricultural and Biosystems Engineering, 9(2), 175–179. https://doi.org/10.5281/zenodo.1099354

13. Arredondo, E., Chiamolera, F. M., Casas, M., & Cuevas, J. (2022). Comparing Different Methods for Pruning Pitaya (Hylocereus undatus). Horticulturae, 8(7), 661. https://doi.org/10.3390/horticulturae8070661
14. Joanna, C. L. Y., & Ding, P. (2021). Floral Morphology and Pollination Process of Red-fleshed Dragon Fruit (*Hylocereus polyrhizus*) Grown in an Open Field. Horticultural Science and Technology, 39(3), 277–293. https://doi.org/10.7235/hort.20210025
15. Clairvil, E., Guimarães, M. D. A., Mário, M. do N., Sartori, L. de J., Rodrigues, F. A., Souza, J. F. F. de, Alves, E., Dória, J., & Pasqual, M. (2025). LED light quality alters the biometrics, bioactive compounds, mineral composition, and anatomy of in vitro micropropagated pitaya. Bragantia, 54(2), 17–37.
16. Khuriyati, N., Fibriato, M. B., & Nugroho, D. A. (2018). Penentuan Kualitas Buah Naga (Hylocereus Undatus) Dengan Metode Non-Destruktif [Non-Destructive Determination of Dragon Fruit (Hylocereus Undatus) Quality]. Jurnal Teknologi & Industri Hasil Pertanian, 23(2), 65–74. https://doi.org/10.23960/jtihp.v23i2.65-74
17. Khoo, H. E., He, X., Tang, Y., Li, Z., Li, C., Zeng, Y., Tang, J., & Sun, J. (2022). Betacyanins and Anthocyanins in Pulp and Peel of Red Pitaya (*Hylocereus polyrhizus* cv. Jindu), Inhibition of Oxidative Stress, Lipid Reducing, and Cytotoxic Effects. Frontiers in Nutrition, 9, 894438. https://doi.org/10.3389/fnut.2022.894438
18. Widodo, W. D., Suketi, K., & Maulida, F. (2020). Studi Degreening, Kesegaran, dan Daya Simpan Buah Naga Merah (*Hylocereus polyrhizus* (Weber) Britton & Rose) untuk Menentukan Kriteria Panen Optimum. Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 48(3), 314–322. https://doi.org/10.24831/jai.v48i3.33065
19. Vargas, M. de L. V., Cortez, J. A. T., Duch, E. S., Lizama, A. P., & Méndez, C. H. H. (2013). Extraction and Stability of Anthocyanins Present in the Skin of the Dragon Fruit (Hylocereus undatus). Food and Nutrition Sciences, 04(12), 1221–1228. https://doi.org/10.4236/fns.2013.412156
20. Al-Mekhlafi, N. A., Mediani, A., Ismail, N. H., Abas, F., Dymerski, T., Lubinska-Szczygeł, M., Vearasilp, S., & Gorinstein, S. (2021). Metabolomic and antioxidant properties of different varieties and origins of Dragon fruit. Microchemical Journal, 160, 105687. https://doi.org/10.1016/j.microc.2020.105687
21. Zitha, E. Z. M., Magalhães, D. S., do Lago, R. C., Carvalho, E. E. N., Pasqual, M., & de Barros Vilas Boas, E. V. (2022). Changes in the bioactive compounds and antioxidant activity in red-fleshed dragon fruit during its development. Scientia Horticulturae, 291, 110611. https://doi.org/10.1016/j.scienta.2021.110611
22. Xiao, L., Shibuya, T., Kato, K., Nishiyama, M., & Kanayama, Y. (2022). Effects of light quality on plant development and fruit metabolism and their regulation by plant growth regulators in tomato. Scientia Horticulturae, 300, 111076. https://doi.org/10.1016/j.scienta.2022.111076
23. Baidya, A., Akter, T., Islam, Md. R., Shah, A. K. M. A., Hossain, Md. A., Salam, M. A., & Paul, S. I. (2021). Effect of different wavelengths of LED light on the growth, chlorophyll, β-carotene content and proximate composition of Chlorella ellipsoidea. Heliyon, 7(12), e08525. https://doi.org/10.1016/j.heliyon.2021.e08525
24. Paśko, P., Galanty, A., Zagrodzki, P., Luksirikul, P., Barasch, D., Nemirovski, A., & Gorinstein, S. (2021). Dragon Fruits as a Reservoir of Natural Polyphenolics with Chemopreventive Properties. Molecules, 26(8), 2158. https://doi.org/10.3390/molecules26082158