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Growing Miniature Waterlilies Under Different Lighting Conditions

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Abstract

An experiment was conducted at the Faculty of Agriculture and Natural Resources, Rajamangala University of Technology Tawan-ok, Chonburi, from July to September 2023. The objective of this research was to determine the optimal growing conditions for *Nymphaea minima* based solely on variations in the color temperature of the LED growth lights. This experiment used five light sources to investigate the growth of *N. minima* rhizomes, including 1) 6500K-LED growth light (6500K-LED), 2) 4500K-LED growth light (4500K-LED), 3) Mixed 6500K + 3500K + 450 nm + 660 nm + 730 nm-LED growth light (Mix LED) and 4) white fluorescent (White-Flu) light sources compared to the control (sunlight). Specimens from each group were planted in a ceramic cup with a 12.7 cm top diameter and a 10.16 cm depth, which was half filled with heavy clay soil. Characterization of the samples was conducted from day 28 to day 84 post-planting to assess growth. Our findings indicate that the responses of *N. minima* to different light qualities diverged from those observed in most terrestrial plants. The leaf count under artificial light treatments did not significantly differ from that under sunlight treatment after 84 days. However, the leaf length, leaf width, and petiole length under sunlight treatment were lower than those under artificial light treatments. The Mix LED treatment exhibited the shortest time to flowering (54.75 days), whereas the White-Flu treatment required the longest duration to reach flowering (75.00 days).

Keywords: Waterlily, Artificial light, Light conditions, Light quality.

1. Introduction

Nymphaea minima is a novel species poised to transform the waterlily industry in the coming years [1]. It is a dwarf lily that grows and thrives in shaded conditions. Most importantly, it transmits these traits to hybrids, enabling the creation of novel miniature varieties. Individuals lacking sufficient space for a pond will be able to grow a waterlily in a container with relative ease in the near future. Growing water lilies indoors can be somewhat challenging, but it is possible with appropriate technical adjustments. Water lilies are aquatic plants that naturally thrive in ponds or other water features where they receive abundant sunlight. If one intends to grow water lilies indoors, it is necessary to create a suitable environment that approximates their natural habitat as closely as possible. LED (Light Emitting Diode) lights are widely used for plant growth in various settings, including indoor gardening and supplemental lighting for outdoor plants. The impact of LED light on plants depends on factors such as the light spectrum, intensity, and duration. Currently, scientists have studied and utilized LED plant growth lamps as lighting for indoor plants [2-4]. Light quality can be produced in different colors according to the needs of the plant [5]. It is essential to research the specific water lily species or variety intended for growth indoors, as different types may have slightly different requirements. Additionally, not all water lilies are suitable for indoor cultivation, so one should select varieties that are known to adapt well to container gardening. While growing water lilies indoors can be a rewarding project, it should be noted that these plants naturally thrive in outdoor environments with access to natural sunlight, so providing suitable conditions indoors can be more complex.

Hence, this study is dedicated to enhancing various indoor lighting options for cultivating *N. minuta*. We hypothesize that *N. minuta*'s response to different light sources might deviate from that of typical terrestrial plants. Instead of investigating light intensity, which has been extensively researched, we concentrate on light quality in this paper. Four artificial light sources were investigated for nurturing *N. minuta* indoors. By analyzing growth traits, the study aims to offer insights for selecting optimal lighting options in the protected cultivation of *N. minuta*.

2. Material and methods

2.1 Experimental design

Four frequently employed artificial light sources—1) white fluorescent (White-Flu), 2) 6500K-LED growth light (6500K-LED), 3) 4500K-LED growth light (4500K-LED), and 4) Mixed 6500K +3500K+450 nm+660 nm+730 nm-LED growth light (Mix LED)—were compared to sunlight (control) in the experiment. The wavelength ranges of various light sources are depicted in Figure 1 (A-E). Table 1 summarizes the photon flux density measured with a quantum PAR meter from a light source height of 30 cm to the water surface level in the cup. Plants were exposed to a 12-h photoperiod daily (6 am–6 pm), with lighting controlled by a timer to automate the activation and deactivation cycles.

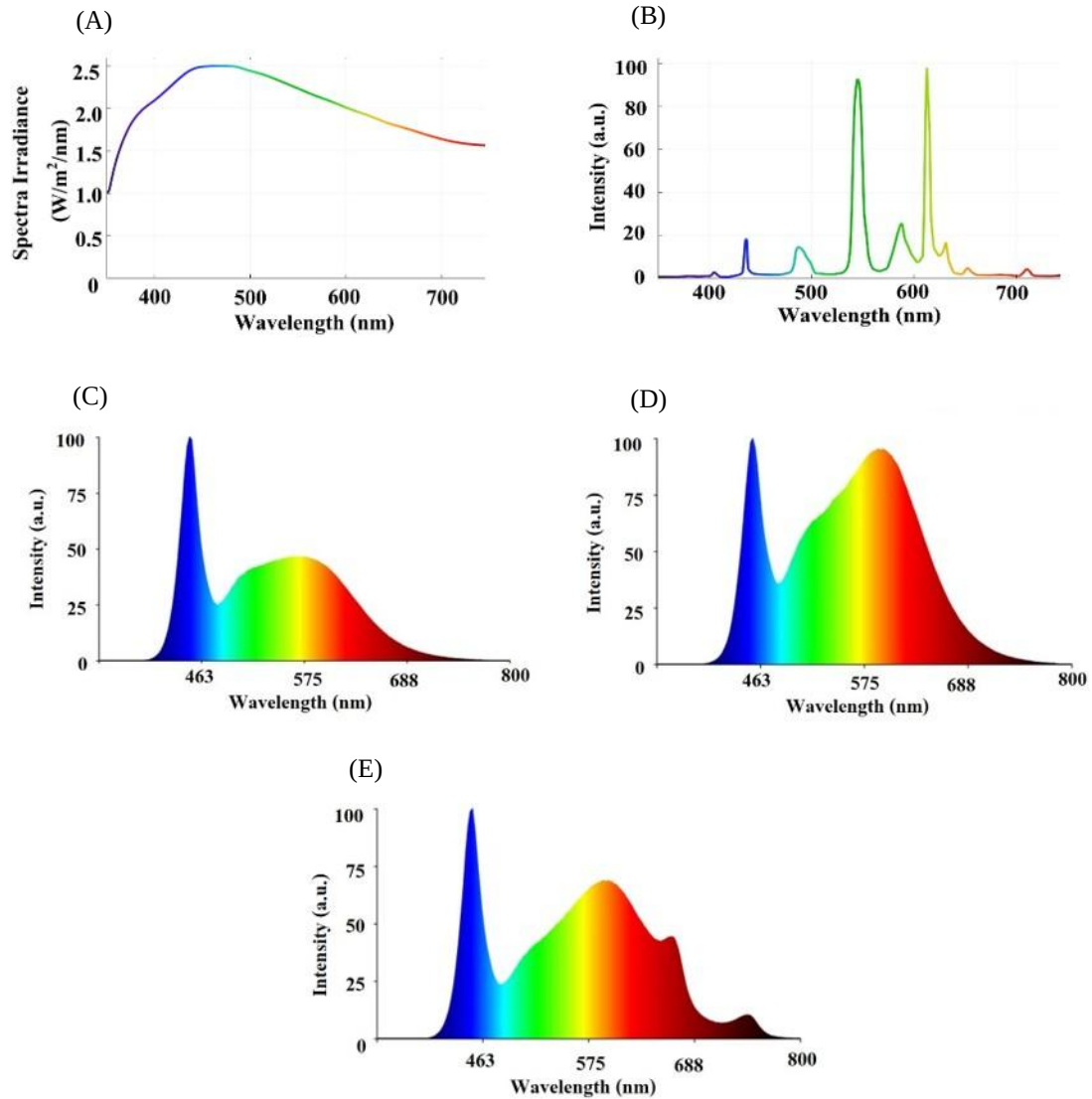


Figure 1 Illustrates the wavelength ranges of various light sources: A is sunlight, B is fluorescent, C is 6500K-LED, D is 4500K-LED and E is Mix LED.

Table 1 The conditions used in the experiment.

Lighting conditions	Photosynthetic Photon Flux Density ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	Temperature ($^{\circ}\text{C}$)	Relative humidity (%)
Sunlight	560-1,400	35.6 $\pm$ 5.5	43.0 $\pm$ 15.4
White-Flu		30.5 $\pm$ 2.4	
4500K-LED	120 $\pm$ 30 $\mu\text{mol m}^{-2} \text{s}^{-1}$	30.8 $\pm$ 2.3	46.3 $\pm$ 8.6
6500K-LED		31.1 $\pm$ 2.5	
Mix LED		32.1 $\pm$ 2.2	

2.2 Plant materials

Rhizomes of *N. minuta* were collected at the Rajamangala Tawan-ok Waterlily Institute, Rajamangala University of Technology Tawan-ok, Chonburi, Thailand. Rhizomes with four fully developed true leaves emerging above the water surface were selected from the nursery pond at the beginning of the experiment. Healthy rhizomes were carefully chosen and individually transplanted into ceramic cups (12.7 cm in diameter and 10.16 cm in depth), with one rhizome per cup filled with clay soil. For each light treatment, a total of 20 cups were utilized. Throughout the experiment, the water level was consistently maintained at 3 cm above the surface of the clay soil. When the plant growth was vigorous, two fertilizer pellets (N-P-K: 16-16-16 fertilizer, Ruela Bai brand) were applied in the rhizosphere at 21 days after transplantation. Additional water was added as the water level receded from 3 cm above the surface of the clay soil. Dead leaves, withered flowers, and their stalks were also removed from the substrate surface.

2.3 Measurements of growth characteristics

After 28 days of growth, the quantities of floating leaves, leaf width, leaf length, petiole length, and flowering age from each cup were recorded every 14 days until reaching 84 days. The data were subjected to statistical analysis using SPSS. Differences among various treatment groups were assessed using one-way ANOVA, followed by multiple comparisons conducted using Duncan's Multiple-Range Test.

3. Results and discussion

Waterlily plants play a vital role in maintaining the health and ecological balance of aquatic ecosystems. Artificial light is increasingly utilized in aquaculture and aquarium settings to support the growth of aquatic plants, ensuring their vitality and contributing to the overall aesthetic appeal of aquatic environments [6].

In the study of average leaf count, it was found that there were statistically significant differences in leaf count at ages 28, 42, and 70 days after transplantation. *N. minuta* grown under all four types of artificial light showed similar growth in leaf count. Light quality affects plant morphology, including stem elongation, leaf expansion, and branching patterns [7]. Meanwhile, *N. minuta* grown under natural sunlight had fewer leaves and differed statistically from those grown under all types of artificial light at ages 28 and 42 days after transplantation (Table 2). This study indicates that the number of leaves of the plants in this study ranged from 6.00 to 13.75 leaves per pot.

Table 2 The average number of leaves at 28, 42, 56, 70 and 84 days after transplanting.

Light conditions	Number of leaves (leaf per cup)				
	28 days	42 days	56 days	70 days	84 days
Sunlight	7.50 ^b	9.00 ^b	7.50	7.00 ^{ab}	6.75
White-Flu	10.50 ^a	13.75 ^a	6.50	8.25 ^a	7.75
4500K-LED	11.25 ^a	13.25 ^a	7.50	7.50 ^{ab}	7.25
6500K-LED	12.00 ^a	13.50 ^a	6.00	7.25 ^{ab}	6.50
Mix LED	12.00 ^a	13.25 ^a	7.00	6.00 ^b	7.25
F-test	*	*	ns	*	ns
C.V. (%)	21.81	19.59	16.22	18.90	14.38

Note: Different lowercase letters indicate significant differences between light treatments ($P < 0.05$)

Generally, plants exhibit a phenomenon known as photomorphogenesis, where light serves as a critical environmental signal that influences various aspects of plant growth and development, including petiole elongation [8]. From Table 3, it can be seen that the average petiole length of *N. minuta* aged 28, 42, 56, 70, and 84 days after transplantation showed similar growth trends under all four types of artificial light. *N. minuta* grown under standard fluorescent light tended to have longer petiole lengths compared to the plants grown under other types of artificial light. This variation stems from differences in the spectral composition of light, where varying proportions of wavelengths such as red, blue, and far-red modulate photoreceptor function and induce specific adaptive responses in plants, leading to petiole elongation. Meanwhile, the plants grown under natural sunlight

exhibited statistically shorter petiole lengths, differing significantly from the plants grown under all types of artificial light, except for those aged 70 days post-transplantation, where there was no statistical difference. Mix LED illumination markedly influences the growth of *N. minuta*, yielding petiole lengths comparable to those observed under natural sunlight (Figure 2). Similar to terrestrial plants, aquatic plants utilize light for photosynthesis, with specific wavelengths playing key roles in their growth and development. Plants growing in low-light conditions or under the shade of taller plants often display shade avoidance responses. These responses include increased elongation of petioles to reach for more light. This is an adaptive strategy to compete for light in a densely vegetated environment [9]. Different wavelengths of light can have varying effects on petiole elongation. For example, red and far-red light are known to play crucial roles in regulating plant growth and development [10]. This corresponds to the results obtained from the Mix LED, which exhibited higher red-light intensity than the other experimental light sources (Figure 1). On the other hand, the experimental results showed a decline in various growth indicators at 56 days after planting, which is likely related to the artificial light environment used in the study. Previous studies have shown that prolonged exposure to artificial light may cause reductions in plant growth, possibly due to altered photosynthetic efficiency or stress responses [11].

Table 3 The petiole length at 28, 42, 56, 70, and 84 days after transplanting.

Light conditions	Petiole length (cm)				
	28 days	42 days	56 days	70 days	84 days
Sunlight	13.85 ^b	14.13 ^b	14.40 ^b	18.38	13.88 ^c
White-Flu	22.05 ^a	21.38 ^a	23.13 ^a	22.38	24.50 ^a
4500K-LED	21.25 ^a	21.30 ^a	19.18 ^{ab}	20.38	23.50 ^{ab}
6500K-LED	17.58 ^{ab}	18.15 ^{ab}	19.70 ^{ab}	21.75	20.25 ^{ab}
Mix LED	16.13 ^b	17.78 ^{ab}	16.60 ^{ab}	19.25	18.75 ^{bc}
F-test	*	*	*	ns	**
C.V. (%)	22.54	19.76	21.96	14.47	24.19

Note: Different lowercase letters indicate significant differences between light treatments ($P < 0.05$)

The study of average leaf width of *N. minuta* aged 28, 42, 56, 70, and 84 days after transplantation revealed similar growth results for the plants grown under all four types of artificial light. In contrast, the plants grown under natural sunlight exhibited statistically narrower leaf widths, differing significantly from those grown under all types of artificial light. At 70 days after transplantation, there was no statistical difference in leaf width among the plants grown under artificial light of all age groups (Table 4 and Figure 3). This study indicates that artificial light does not significantly affect *N. minuta* growth in terms of leaf width. From Table 5, it can be seen that there is a correlation between the length of *N. minuta* leaves and the time period after planting. *N. minuta* grown under artificial light exhibits similar growth in leaf length at ages 28, 42, 56, 70, and 84 days after transplantation. At 56 and 70 days after transplantation, there is no statistically significant difference in leaf width. From this experiment, the plants grown under artificial light showed reduced growth in leaf length. The results of leaf width and leaf length indicate that the plants grown under artificial light exhibit slightly different outcomes but generally higher averages compared to those grown under natural sunlight (Figure 3). Therefore, growing *N. minuta* under artificial light may affect leaf width and leaf length growth to some extent. Terashima et al [12] also demonstrated the importance of balanced light spectra in maximizing photosynthetic rates and promoting optimal leaf expansion. Exposure to different light spectra can induce specific anatomical changes in plants, enhancing their capacity to absorb and utilize light efficiently. Smith et al [13] examined the effects of light quality on leaf anatomy and physiological performance, providing insights into the adaptive responses of plants to varying light conditions. Light intensity and penetration depth are critical factors influencing aquatic plant growth, especially in submerged environments, such as the significance of optimizing light intensity to ensure adequate irradiance reaches submerged plant communities, thereby sustaining their growth and productivity [14].

Table 4 The leaf width at 28, 42, 56, 70 and 84 days after transplanting

Light conditions	Leaf width (cm)				
	28 days	42 days	56 days	70 days	84 days
Sunlight	3.68 ^b	3.73 ^b	3.80 ^b	4.28 ^b	3.75 ^b
White-Flu	5.18 ^{ab}	5.48 ^a	5.13 ^a	5.35 ^a	5.03 ^{ab}
4500K-LED	5.25 ^a	4.83 ^{ab}	4.78 ^{ab}	5.40 ^a	5.35 ^a
6500K-LED	5.90 ^a	5.35 ^a	5.25 ^a	5.63 ^a	5.00 ^{ab}
Mix LED	5.63 ^a	5.80 ^a	5.33 ^a	5.65 ^a	4.85 ^{ab}
F-test	*	*	*	*	*
C.V.(%)	23.84	20.76	20.07	15.25	18.99

Note: Different lowercase letters indicate significant differences between light treatments ($P < 0.05$)

Table 5 The leaf length at 28, 42, 56, 70 and 84 days after transplanting

Light conditions	Leaf length (cm)				
	28 days	42 days	56 days	70 days	84 days
Sunlight	4.60 ^b	4.73 ^b	4.65	5.13	4.38 ^b
White-Flu	5.83 ^{ab}	6.03 ^a	5.73	5.85	5.28 ^{ab}
4500K-LED	5.98 ^{ab}	5.30 ^{ab}	5.60	5.53	5.78 ^{ab}
6500K-LED	6.55 ^a	6.05 ^a	5.83	5.80	5.98 ^a
Mix LED	6.25 ^a	6.20 ^a	5.83	6.18	5.15 ^{ab}
F-test	*	*	ns	ns	*
C.V.(%)	18.02	16.11	15.88	12.46	18.03

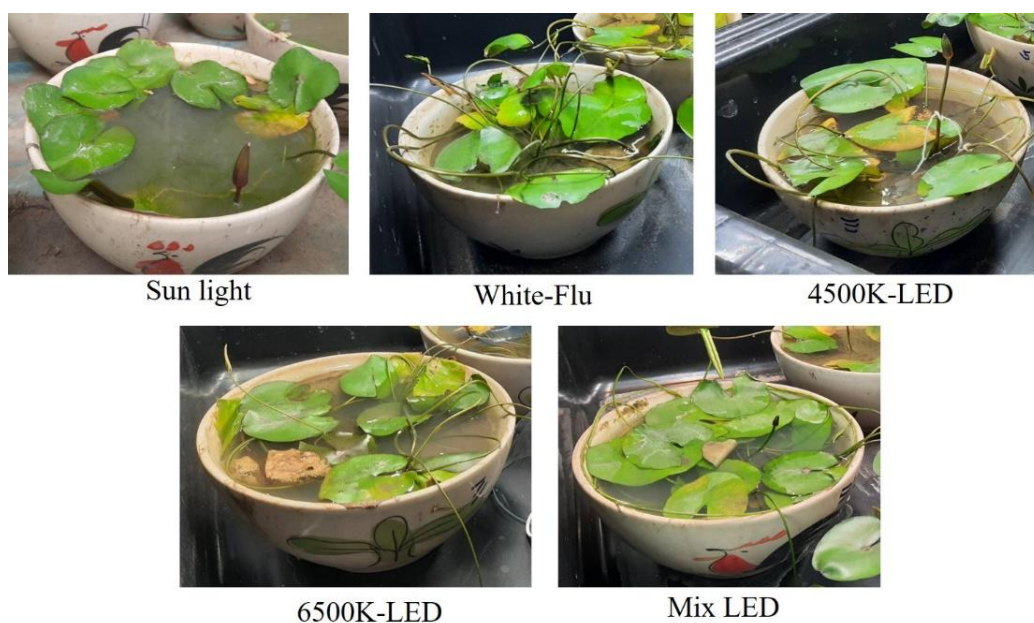
Note: Different lowercase letters indicate significant differences between light treatments ($P < 0.05$)

Light is another crucial factor in growing *N. minuta* optimally. The plants require direct sunlight for at least 5-6 hours per day to facilitate photosynthesis and utilize soil nutrients for optimal growth, leaf spreading, and prolific flowering [15]. From the study results, it was found that the flowering age of the plants differed statistically. *N. minuta* grown under Mix LED light had flowering ages comparable to natural sunlight, while those grown under standard white-fluorescent light had delayed flowering compared to other methods (Table 6). Regarding the count of flowers after the first flowering until 84 days after planting, it was found that the number of flowers was relatively similar. The plants grown under Mix LED light had the highest average number of flowers at 4.25 flowers per pot, while those grown under standard white-fluorescent light had the lowest average at 2.25 flowers per pot. This study indicates that Mix LED light results in *N. minuta* having flowering ages and flower counts comparable to those grown under natural sunlight. The importance of specific light spectra in enhancing photosynthetic efficiency and overall plant growth [16]. This phenomenon may be attributed to differences in spectral characteristics between the LED source and the fluorescent source, encompassing both wavelength range and the relative abundance of specific wavelengths.

Table 6 The flowering age and number of flowers of *N. minuta*.

Light conditions	Flowering age (days)	Number of flower (flower per pot)
Sunlight	55.25 ^{bc}	3.75 ^{ab}
White-Flu	75.00 ^a	2.25 ^b
4500K-LED	65.75 ^{ab}	3.75 ^{ab}
6500K-LED	59.25 ^b	3.25 ^{ab}
Mix LED	54.75 ^c	4.25 ^a
F-test	*	*
C.V.(%)	15.83	33.19

Note: Different lowercase letters indicate significant differences between light treatments ($P < 0.05$)

**Figure 2** Waterlily planted under different lighting conditions at 84 days after transplanting.

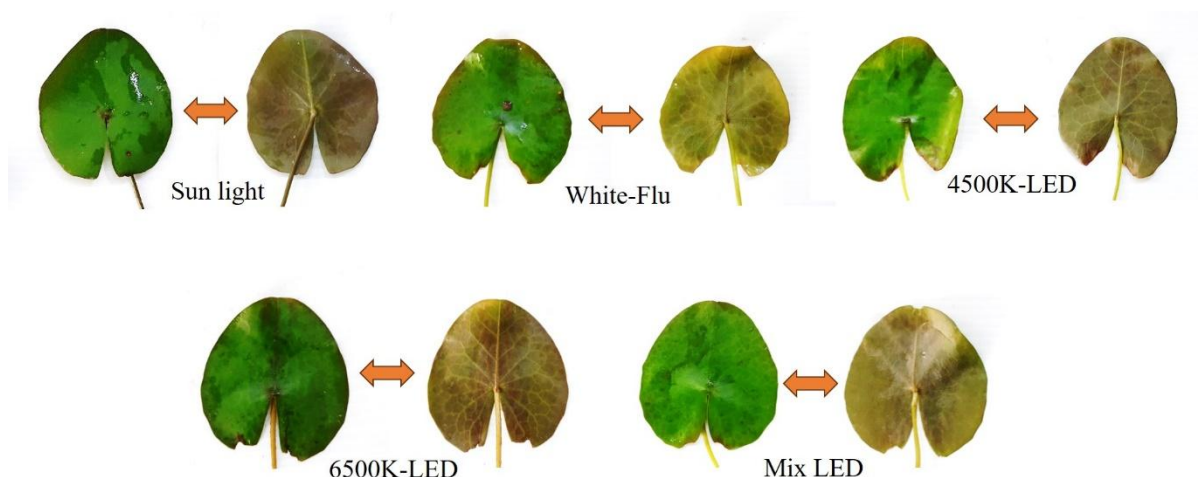


Figure 3 Show the color on the upper and lower surfaces of the leaves of *N. minuta* under different light conditions.

The variations in *N. minuta* growth under different light regimes can likely be attributed to the specific physiological functions of red and blue wavelengths in regulating plant development. Red wavelengths enhance chlorophyll biosynthesis, photosystem activity, and leaf expansion, resulting in improved photosynthetic product accumulation [17]. Blue light, by contrast, plays a crucial role in stomatal regulation, as it promotes stomatal opening and thereby enhances CO₂ uptake and photosynthetic efficiency [18]. In addition, blue wavelengths are closely linked to the synthesis of anthocyanins and other protective pigments that contribute to photoprotection and stress tolerance [19]. The synergistic effects of red and blue light may underlie the greater pigment accumulation, enhanced leaf development, and improved growth performance recorded under mixed LED conditions compared to white, fluorescent light. Collectively, these findings highlight that *N. minuta*, like other aquatic plants, is sensitive to light spectrum, and that a balanced combination of red and blue wavelengths may provide the most favorable conditions for photosynthetic activity and growth.

4. Conclusion

Our findings reveal that *N. minuta* benefits most from mixed red and blue LED light, which enhanced pigment content, leaf development, and overall growth compared with white, fluorescent light. The complementary roles of red light in promoting chlorophyll formation and photosynthesis, and blue light in stimulating stomatal activity and pigment biosynthesis provide a clear explanation for these responses. This study improves understanding of the light requirements of *N. minuta* and highlights the potential of tailored LED spectra to optimize indoor waterlily cultivation.

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6. Author Contributions

Conceptualization: A.C., N.S.; Methodology: A.C., R.M.; Investigation: A.C., R.M.; Resources: R.M.; Data curation: R.M., M.A.; Formal analysis: M.A.; Writing – original draft: A.C.; Writing – review & editing: A.C., R.M., M.A., N.S.; Project administration: N.S.; Funding acquisition: N.S.; All authors have read and agreed to the published version of the manuscript.

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