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THE POWER OF BLUE LIGHT: INCREASING CHLOROPHYLL CONTENT IN EARLY STAGES OF AVOCADO (*PERSEA AMERICANA* MILL) SEEDLINGS

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Abstract

This study investigates the impact of blue light exposure on the chlorophyll content of avocado (*Persea americana* Mill.) seedlings during their early growth stages. As the global demand for avocados increases, the need for efficient propagation of healthy seedlings has become critical. Chlorophyll, a vital pigment involved in photosynthesis, plays a key role in seedling growth and overall plant vigor. This research explores the use of LED lights, specifically blue light, to enhance chlorophyll production in avocado seedlings, potentially accelerating seedling growth and improving their health. The experiment was conducted in a nursery in Dologon, Maramag, Bukidnon, where seedlings were exposed to three different artificial light treatments: red, blue, and white light, alongside a control group receiving natural sunlight. The study employed a 4 x 3 split plot arrangement in a Randomized Complete Block Design (RCBD), measuring chlorophyll content using a FieldScout CM 1000 Chlorophyll Meter. Results showed that blue light exposure significantly increased chlorophyll content in avocado seedlings compared to other treatments, with the highest chlorophyll levels recorded in the blue light group. This effect was most pronounced in the Evergreen cultivar, which demonstrated the highest chlorophyll content across all treatments. The red and white light treatments also showed improvements in chlorophyll content, though to a lesser extent than blue light. The findings suggest that blue light exposure can be an effective method for enhancing chlorophyll production and promoting healthier, more vigorous avocado seedlings, offering a valuable tool for improving avocado propagation practices in nursery settings.

Keywords: Avocado Seedlings, Blue Light Exposure, Chlorophyll Content, Led Lighting, Photosynthesis Enhancement.

INTRODUCTION

Avocado (*Persea americana* Mill.) is one of the most economically important fruit crops globally, widely recognized for its rich nutritional profile, health benefits, and high content of healthy fats, vitamins, and minerals (Stephen & Radhakrishnan, 2022; Bhore et al., 2021).

The avocado industry has experienced significant growth due to increasing demand, driven by its versatility in culinary applications and its health-promoting properties. Food and Agriculture Organization (2021) reported that global avocado exports increased by 8.2%, reaching approximately 2.3 million tons from 2019 to 2020.

This rising demand, however, presents challenges in meeting the global need for quality planting materials, particularly in regions with favorable climates such as Mexico, the United States, and parts of South America and Africa. The availability and quality of healthy, vigorous seedlings are crucial to meeting this demand and ensuring successful propagation and fruit-bearing (Singh et al., 2024; Global Affairs Canada, 2018).

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Despite the growing popularity of avocados, the production of high-quality seedlings remains constrained by factors such as lack of access to high-quality avocado seeds and planting materials (Asfaw & Nigussie, 2024; Bugudole et al., 2025), inadequate farmer skills and knowledge of production, and prevalence of pests and diseases (Kiros, 2008), climate variability (Sina et al., 2024; Seid et al., 2023), inefficient nursery practices (Bugudole et al., 2025; Juma et al., 2019), and slow growth during the early developmental stages (Foufou et al., 2024). These challenges highlight the urgent need for innovative solutions that can accelerate seedling growth, enhance seedling health, and increase the efficiency of avocado propagation. A crucial factor affecting seedling growth is chlorophyll content, a vital pigment involved in photosynthesis (Talebzadeh & Valeo, 2022; Wang et al., 2022). Chlorophyll plays a key role in enhancing photosynthetic efficiency, which leads to faster and healthier growth. Increased chlorophyll content is also associated with improved nutrient assimilation (Li et al., 2020), better drought resistance, and enhanced plant vigor (Zhou et al., 2023; Yue et al., 2024). Therefore, maintaining optimal chlorophyll levels in avocado seedlings during their early growth stages is essential for successful establishment and long-term development.

Recent advancements in agricultural technology, particularly the use of LED growth lights, have shown promising results in optimizing light spectra to improve plant growth (Sena et al., 2024; Alrajhi et al., 2023). Among the various light wavelengths, blue and red lights have been shown to promote photosynthesis effectively (Liu & van Iersel, 2021; Shuai et al., 2016). Specifically, blue light has been found to stimulate chlorophyll production and enhance nutrient absorption (Miao et al., 2016), whereas red light supports overall plant growth and flowering (Kong & Nemali, 2021). The use of LED lights with specific wavelengths, such as blue light, has proven effective in increasing chlorophyll content in seedlings, thus improving their propagation and accelerating growth. This technology has revolutionized plant growth in controlled environments, offering a potential solution for improving seedling production (Livadariu et al., 2023; Al Murad et al., 2021; Gómez & Izzo, 2018), including avocado. By optimizing light exposure during the early stages of seedling growth, it is possible to enhance chlorophyll content, leading to more productive and efficient avocado seedling propagation.

Despite the promising results from LED lighting research, limited attention has been given to how blue light exposure specifically impacts avocado seedling growth, particularly in the early stages. While studies have focused on the general effects of light wavelengths on plant growth, little is known about the potential benefits of blue light for enhancing chlorophyll content in avocado seedlings. This study aims to explore the effects of blue light exposure on the chlorophyll content of avocado seedlings during their early growth stages. By investigating blue light as a tool for enhancing chlorophyll production, this research seeks to provide valuable insights into how LED lighting can be integrated into avocado nursery practices, ultimately promoting healthier seedlings and contributing to the overall sustainability of the avocado industry.

The findings of this research have the potential to make a significant contribution to global avocado production by optimizing seedling propagation practices. As demand for avocados continues to rise, especially in regions with limited access to quality planting materials, this

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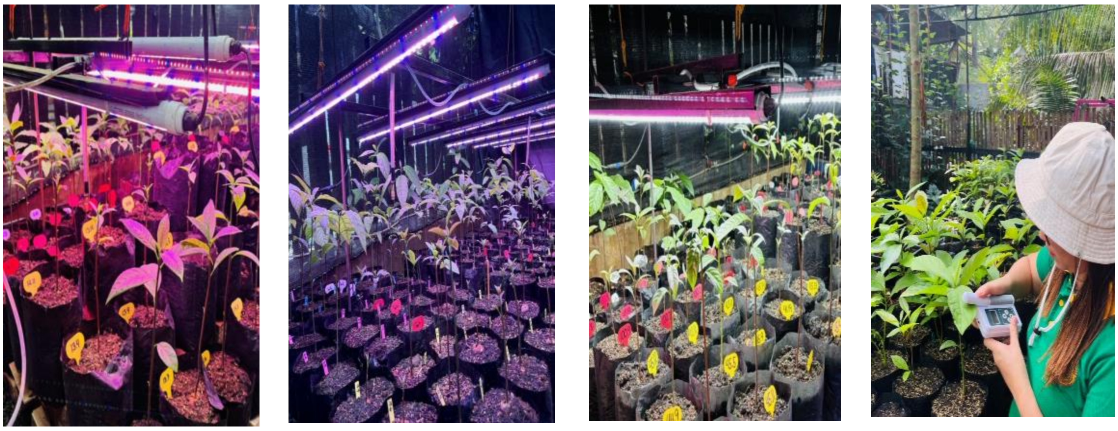
study offers an innovative approach to enhancing seedling health and growth. By demonstrating the positive effects of blue light exposure on chlorophyll production in avocado seedlings, this research can serve as a guide for improving nursery practices worldwide. The use of LED technology to accelerate seedling growth not only enhances the efficiency of avocado propagation but also offers a sustainable solution to meet the increasing demand for high-quality avocados. This research could ultimately help reduce the time and resources needed to produce healthy seedlings, thereby supporting the avocado industry's growth, sustainability, and global food security.

MATERIALS AND METHODS

The in vivo study was conducted in a plant nursery in Dologon, Maramag, Bukidnon (7°50'11.21"N;125°2'29.65"E) from May to December 2024. The nursery was divided into four separate sections for each LED light which served as Main-plots. HortiPower Singapore's Nurser 4 (30W/pc) Led lights were installed to illuminate the nursery in three colors: red (Figure 1), blue (Figure 2), and white (Figure 3), for an 8-hour photoperiod, seven days per week. The seedlings exposed to natural light or sunlight served as the Control.

Seeds of avocado consisting three cultivars (Sub-plots) were gathered and grown in a sterilized coco peat-based growing medium (Figure 2a). After 14 days, germinated seeds (Figure 2b) were placed to polyethylene bags containing a 1:1:1:1 mixture of garden soil, compost, vermicast, and rice hull. Complete slow-release fertilizer was added to the soil media. The seedlings were then selected and standardized to achieve the five sample plants per treatment per replication, and subsequently positioned in the nursery according to the artificial light treatments that have been assigned.



(a) (b) (c) (d)

Figure 1: Nurser 4 LED lights in (a) red, (b) blue, and (c) white colors manufactured by HortiPower Singapore were used as artificial lights inside the nursery, whereas (d) plants exposed to natural light or sunlight served as Control

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For irrigation, a misting system was installed around the nursery and experimental area. The plants were misted daily for the first 2 months of growth, and then every three to four days or depending on their needs in the next consecutive months considering the rainy and dry seasons. Fertilization was performed using a complete fertilizer at a rate of 5 g/L, applied by drenching 250 mL per plant every 15 days during the first three months (July to September), and once a month thereafter. In addition, fungicides and insecticides were applied whenever necessary to prevent and control potential pest infestations and fungal diseases.

(a) (b) (c) (d)

Figure 2: (a) Avocado seeds cultivated in a coco-peat-based medium; (b) Germinated avocado seed showing early root development; (c) Field Scout CM 1000 Chlorophyll Meter® used for chlorophyll content measurement; (d) Measurement of chlorophyll content in avocado leaf using the Field Scout CM 1000.

Chlorophyll content in the seventh leaf of the seedlings, counting from the roots towards the top, was measured using a Field Scout CM 1000 Chlorophyll Meter® [FieldScout Spectrum Technologies, Inc., IL, USA (Figure 2c)]. Measurement of chlorophyll content (Figure 2d) commenced 2 months after seed germination.

Analysis of Variance for a 4 x 3 split-plot arrangement within a Randomized Complete Block Design (RCBD) was performed using SAS (The Statistical Analysis System) v.9.1.2., and was verified using STAR (Statistical Tool for Agricultural Research) v.2.0.1. Tukey's Honestly Significant Difference (HSD) Test was applied to compare treatment means, with significance set at $P < 0.05$.

RESULTS AND DISCUSSION

Chlorophyll content (SPAD units)

The data presented in Table 1 shows the chlorophyll content (measured in SPAD units) of avocado seedlings exposed to different light treatments over a period of five months (August to December 2024). The light treatments include Control (natural light), Red, Blue, and White light, while the cultivars include Malagkit, Hass, and Evergreen.

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Table 1: Chlorophyll content of three avocado (*Persea americana* Mill) cultivars in response to artificial LED lights for five months from August to December 2024

Treatments	Chlorophyll Content (SPAD units)				
	1st Month	2nd Month	3rd Month	4th Month	5th Month
Main Plot (Light)					
Control	9.96b	12.09b	10.49b	11.66b	46.05a
Red	13.19ab	15.20ab	13.32ab	18.36a	48.75a
Blue	18.01a	20.33a	18.82a	19.66a	51.56a
White	15.67ab	18.33a	15.64ab	16.75a	38.21a
F-Test	**	**	**	*	*
CV (a)%	28.07	20.14	27.64	31.12	23.29
Subplot (Cultivar)					
Evergreen	15.28	18.75a	15.98	15.67	49.10
Hass	13.48	16.05ab	13.45	17.55	43.44
Malagkit	13.85	14.66b	14.26	16.61	45.89
F-Test	ns	*	ns	ns	ns
CV (b)%	17.30	15.82	17.55	25.44	15.83

Means within a column and their interactions followed with the same letters are not significantly different from each other according to Tukey's Honest Significant Difference (HSD)

ns = not significant; ** - significant at 1% level; * - significant at 5% level (F-Test)

Light Treatment Effects on Chlorophyll Content

The analysis of the experimental data reveals that the Blue light treatment had a consistent and significant positive effect on chlorophyll content throughout the duration of the study. In the first month, the Blue light-treated seedlings exhibited an initial chlorophyll reading of 18.21 SPAD units, which was already higher compared to other light treatments. This initial increase suggests that the Blue light treatment started to enhance the chlorophyll content shortly after exposure, indicating an immediate response in the seedlings.

In the second month, the chlorophyll level reached 20.33 SPAD units, showing an improvement of nearly 2 SPAD units compared to the first month. This increase suggests that Blue light has a cumulative effect over time, consistently stimulating chlorophyll production as the seedlings grew and developed. In the third month, while the chlorophyll content decreased slightly to 18.82 SPAD units, it still remained higher than the levels observed in the red, white light, and control groups. By the fourth month, the chlorophyll content increased again to 19.66 SPAD units. The most remarkable increase occurred in the fifth month, where the Blue light group peaked at 51.56 SPAD units. This significant spike suggests that Blue light exposure had a lasting and strong influence on chlorophyll synthesis (Balint et al., 2021; Senger, 1982), resulting in a substantial enhancement of photosynthetic efficiency. The data clearly indicates that Blue light exposure consistently promoted higher chlorophyll production (Jin et al., 2023; Zittelli et al., 2022). The Red light treatment showed an increase in chlorophyll content, particularly in the second month, where seedlings recorded 15.20 SPAD units, and again in the fourth and fifth month, reaching 18.36 and 48.75 SPAD units. respectively. While this increase

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suggests that Red light can effectively stimulate chlorophyll production, the overall response was less consistent compared to the Blue light treatment. In some months, such as the third month, Red light exhibited a slight drop in chlorophyll content, highlighting its variability in promoting chlorophyll synthesis. Despite these fluctuations, Red light still demonstrated the ability to enhance chlorophyll content, but it did not achieve the same steady increase observed in the Blue light treatment. The implication of these findings is that while Red light can be beneficial for chlorophyll production (Nadalini et al., 2017), it is less reliable than Blue light for ensuring consistent and sustained improvements (Miao et al., 2016) in avocado seedling growth, suggesting that Blue light is the more effective option for optimizing chlorophyll content and promoting healthier seedling development (Wei et al., 2023; Johkan et al., 2010).

The White light treatment exhibited variable effects on chlorophyll content throughout the study period. In the first month, the chlorophyll content was relatively high at 15.67 SPAD units, and in the second month, it increased to 18.33 SPAD units, suggesting that White light initially had a positive impact on chlorophyll production. However, as the experiment progressed, the chlorophyll content showed a noticeable decline, particularly in the fifth month, where it dropped to 38.21 SPAD units. This decline indicates that while White light may enhance chlorophyll content in the short term (Ke et al., 2024), its effectiveness diminishes over time (Seyedi et al., 2024), making it less reliable for sustained chlorophyll enhancement. The implication of these findings is that White light may not be as effective as Blue or Red light for long-term stimulation of chlorophyll production (Tarakanov et al., 2022; Metallo et al., 2018) in avocado seedlings, suggesting that other light treatments may be more suitable for promoting consistent seedling growth and health (Chen et al., 2024; Degni et al., 2021).

The Control group, which received no supplemental light, exhibited relatively low chlorophyll content throughout the experimental period. The lowest chlorophyll level was recorded in the first month at 9.96 SPAD units, indicating minimal chlorophyll production during this phase. However, by the fifth month, the chlorophyll content increased to 46.05 SPAD units, showing some natural accumulation of chlorophyll over time. Despite this increase, the chlorophyll levels in the Control group were still much lower than those observed in the light treatments (except on the fifth month), suggesting that while natural light can contribute to chlorophyll production, it is less effective than the artificial light treatments in promoting significant chlorophyll enhancement. These results imply that supplemental light, particularly Blue or Red, is essential for optimizing chlorophyll content (Holweg et al., 2024; Yindeesuk et al., 2021) and supporting healthier, more vigorous (Matysiak & Kowalski, 2019; Nawaz et al., 2018) avocado seedling growth.

Cultivar Effects on Chlorophyll Content

Across the three avocado cultivars, the Evergreen cultivar consistently exhibited the highest overall chlorophyll content. It recorded the highest chlorophyll levels in the first month at 15.20 SPAD units and in the fifth month at 49.10 SPAD units, showcasing its ability to maintain robust chlorophyll production throughout the experimental period. Compared to the other two cultivars, Malagkit and Hass, the Evergreen cultivar displayed more stable chlorophyll levels, with less fluctuation across the months.

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This stability suggests that Evergreen may have a stronger or more consistent response to the light treatments, particularly Blue light, which contributed to its higher chlorophyll content (Li et al., 2020; Zheng & Van Labeke, 2017). The findings imply that cultivar type plays an important role in the effectiveness of light treatments (Wadood et al., 2023; Chutimanukul et al., 2022), and the Evergreen cultivar may be a more suitable choice for avocado seedling propagation under controlled light conditions.

The Malagkit cultivar displayed moderate chlorophyll content throughout the experimental period, with the highest recorded in the fifth month at 45.89 SPAD units and the lowest in the first month at 13.85 SPAD units. This fluctuation indicates that the Malagkit cultivar responded more variably to the light treatments compared to the Evergreen cultivar, which showed more consistent chlorophyll production.

The marked decrease in chlorophyll content in the first month suggests that the Malagkit cultivar might be more sensitive to changing environmental conditions or light exposure. Despite this fluctuation, Malagkit still showed a reasonable level of chlorophyll content, particularly when exposed to Blue light, but its overall response was less stable than that of the Evergreen cultivar. This variability highlights the importance of cultivar selection among plants in optimizing light treatment strategies (Lee et al., 2019; Rowe & Paul, 2012).

The Hass cultivar consistently exhibited the lowest chlorophyll content throughout the experimental period, with the lowest recorded in the third month at 13.45 SPAD units and a modest increase to 17.55 SPAD units in the fourth month. Although there was a slight increase in chlorophyll content by the fifth month, reaching 43.44 SPAD units, it still remained lower than the levels observed in the Evergreen cultivar. This suggests that while the Hass cultivar responded to the light treatments, particularly Blue light, its overall chlorophyll production was less pronounced compared to the other two cultivars, Evergreen and Malagkit.

The findings indicate that the Hass cultivar may have a slower or less efficient response to light exposure, which could impact its growth and development under controlled light conditions. Despite the increase in chlorophyll content by the fifth month, the Hass cultivar still lagged behind in comparison to the other cultivars, highlighting its relatively lower potential for enhanced chlorophyll production under these experimental conditions.

Table 2: Interaction effects of light and cultivar on the chlorophyll content of avocado seedlings at two months after seed germination

Treatments	Chlorophyll Content (SPAD units)			
	Control	Red	Blue	White
Evergreen	$12.59^{A,a}$	$15.58^{A,a}$	$23.39^{A,a}$	$23.54^{A,a}$
Hass	$13.29^{A,b}$	$13.82^{A,b}$	$21.49^{A,ab}$	$15.59^{AB,a}$
Malagkit	$10.47^{B,b}$	$10.19^{B,b}$	$16.13^{A,a}$	$15.85^{A,a}$

Uppercase letters indicate statistically significant difference among cultivars (subplot) at each light treatment level (main plot). Lowercase letters represent statistically significant differences among light treatments (main plot) at each cultivar level (subplot) according to Tukey's HSD at significant level of 5% (F-Test)

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Light Treatment Effects on Chlorophyll Content:

At the control level, the chlorophyll content of avocado seedlings shows some variation among the different cultivars. Malagkit has the lowest chlorophyll content, recording 10.47 SPAD units. Hass, on the other hand, stands out with the highest chlorophyll content at 13.29 SPAD units. Evergreen falls in between, with a value of 12.59 SPAD units. Hass and Evergreen have similar chlorophyll content at the control level which is significantly different from Malagkit, displaying a lower chlorophyll content. These differences in chlorophyll content are statistically significant based on Tukey's HSD test, which shows that Hass and Evergreen perform better at the control level than the other cultivars. The differences in chlorophyll content among avocado cultivars have practical implications for growers. Hass, with the highest chlorophyll content, shows that plants with better photosynthetic efficiency are more resilient in areas with sufficient light (Sembada et al., 2024; Li et al., 2023). Malagkit, with the lowest chlorophyll content, may require improved environmental conditions to optimize growth. Evergreen falls between the two, suggesting moderate adaptability. These findings can help farmers select the most suitable cultivar based on local light conditions, optimizing growth and productivity (VanDerZanden, 2024; Duza, 2020; Belew, 2019).

At the Red light level, the chlorophyll content among the avocado cultivars reveals notable differences. Evergreen has the highest chlorophyll content at 15.58 SPAD units, followed by Hass at 13.82 SPAD units. Both of these cultivars show no significant difference from each other, indicating similar performance under red light conditions. On the other hand, Malagkit still has the lowest chlorophyll content at 10.19 SPAD units, suggesting that it has a lesser photosynthetic response to red light compared to the other two. The practical implication of these results is that Evergreen and Hass may be more adaptable and efficient under red light exposure, making it a potentially better choice for environments where red light is a dominant factor (Rosniza et al., 2023; Thornton et al., 2023). While Malagkit may require adjustments in growing conditions to optimize it chlorophyll production (Jung & Arar, 2023; Ma et al., 2010) under these light conditions.

At the Blue light level, there are no significant differences in the chlorophyll content among the avocado cultivars. Malagkit has a chlorophyll content of 16.13 SPAD units, which is lower than Evergreen and Hass, but still relatively high compared to its performance at other light levels. Hass performs better with 21.47 SPAD units, and Evergreen shows the highest chlorophyll content at 23.39 SPAD units, making it the most efficient under blue light conditions. These results suggest that Evergreen is the most efficient cultivar in terms of photosynthesis when exposed to blue light, while Hass also performs well, though not as highly as Evergreen. Malagkit, on the other hand, lags behind, indicating that it may require specific adjustments or more favorable conditions to optimize its chlorophyll content under blue light. These findings can help guide farmers in choosing the most suitable plant cultivar for environments with higher blue light exposure (Arif et al., 2024; Wang et al, 2022).

At the White light level, there are slight differences in the chlorophyll content of the avocado cultivars. Evergreen leads with the highest chlorophyll content at 23.54 SPAD units, demonstrating the best photosynthetic efficiency under white light conditions. Malagkit follows with 15.85 SPAD units, showing a moderate performance compared to Evergreen, but still better than Hass, which has the lowest chlorophyll content at 15.59 SPAD units. The results indicate that Evergreen and Malagkit are more efficient cultivar in terms of chlorophyll production under white light, suggesting it may be more adaptable and productive in environments with such light conditions. While Hass still lags behind the two cultivars implying that Hass may require specific adjustments or more favorable conditions to optimize its performance under white light. It is imperative, therefore, to select the most suitable cultivar for regions with higher white light exposure, potentially improving growth and yield (Choi et al., 2022; Sharakshane, 2018).

From a theoretical perspective, the study highlights how different avocado cultivars respond to varying light conditions, providing insight into the physiological adaptability of each cultivar. The variation in chlorophyll content under different light levels suggests that certain cultivars, like Evergreen, are better suited for specific light conditions (Wu et al., 2025; Miao et al., 2023), enhancing photosynthetic efficiency. These findings contribute to the understanding of plant-light interactions and can inform future studies on how light affects avocado growth and yield.

Practically, these results can guide avocado growers in selecting the most suitable cultivar based on their local light conditions. For example, Evergreen performs well across all light conditions, indicating that it may be a better choice for any area. Hass, which performs well in the three light treatments (control, blue light, and red light) may be favored in regions with more consistent natural light, as well as artificial lights (red and blue), except for white light. Malagkit, with its lower performance across the board, may require more optimal growing conditions or light management strategies to achieve higher chlorophyll production and better growth (Benavente-Valdés et al., 2016; Fu et al., 2012). Growers can use this information to optimize their crop selection and improve yield by choosing cultivars that are better adapted to their specific environmental conditions, ultimately enhancing the efficiency of avocado production.

These findings also underscore the importance of light manipulation in controlled environments, such as greenhouses, where growers can optimize light conditions to suit the specific needs of different avocado cultivars (Villagran et al., 2025; Rahman et al., 2021; Xin et al., 2019).

CONCLUSION

In conclusion, the results of this study highlight the significant role of light exposure, particularly Blue light, in enhancing the chlorophyll content of avocado seedlings. The Blue light treatment proved to be the most effective in promoting chlorophyll production, with Hass and Evergreen cultivars showing marked increases in chlorophyll content under this light. Evergreen seedlings, in particular, demonstrated the highest chlorophyll content across all light treatments, indicating its superior response to light exposure and suggesting that certain cultivars may be more adaptable to specific light conditions. The Red and White light treatments also showed improvements in chlorophyll content, but these were not as pronounced

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or consistent as the effect of Blue light. The Control group, which received natural sunlight, exhibited the lowest chlorophyll content, reinforcing the idea that supplemental lighting, particularly Blue light, plays a crucial role in enhancing photosynthetic efficiency during the early stages of seedling growth.

These findings have important practical implications for avocado growers. Blue light exposure can be used strategically in nursery settings to optimize seedling growth and improve the health of avocado plants, especially in regions with limited natural light or in controlled environments like greenhouses. The study also suggests that Evergreen, with its stable and high chlorophyll content, may be a particularly suitable cultivar for environments where artificial lighting is used. On the other hand, Hass and Malagkit, while showing positive responses to Blue light, may require more specific environmental adjustments to achieve similar levels of chlorophyll content as Evergreen.

Overall, this research underscores the importance of optimizing light exposure for avocado seedlings, with Blue light emerging as the most effective light treatment for promoting chlorophyll production. By integrating LED light treatments into nursery practices, avocado propagation can be enhanced, leading to healthier, more vigorous seedlings and potentially higher yields in the long term.

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Conflict of interest

The authors declare no conflict of interest.

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