RESEARCH ARTICLE

Growth and photosynthetic pigments of *Licania tomentosa*, *Syzygium cumini*, and *Tabebuia serratifolia* seedlings under different wavelengths

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ABSTRACT

Licania tomentosa (Benth.) Fritsch, *Syzygium cumini* (L.) Skeels, and *Tabebuia serratifolia* (Vahl) G. Nicholson are commonly used in urban landscaping, particularly in public squares, major avenues, and parks. Therefore, producing and developing high-quality seedlings of these species is paramount. This study evaluated the growth and photosynthetic pigments of *L. tomentosa*, *S. cumini*, and *T. serratifolia* seedlings under different wavelengths generated by colored cultivation benches. The cultivation benches assessed included glossy blue, red, white, and yellow surfaces and a control treatment without any colored material. The wavelengths reflected by these colored surfaces positively influenced the growth and quality of *L. tomentosa*, *S. cumini*, and *T. serratifolia* seedlings, as well as the photosynthetic pigments of *T. serratifolia*. For producing high-quality *L. tomentosa* seedlings, blue, white, and yellow cultivation benches, particularly the white and yellow, proved most effective, which increased quality by 16% and 21%, respectively. The different wavelengths did not enhance the photosynthetic pigment content of *L. tomentosa* and *S. cumini* seedlings. For *S. cumini*, the yellow cultivation bench yielded the best biometric quality, followed by the blue bench, which increased quality by 22% and 14%, respectively. In the case of *T. serratifolia*, colored cultivation benches, especially red, white, and yellow, resulted in superior seedling quality, which increase7d quality by 11%, 15%, and 14%, respectively. Moreover, the light spectra provided by the blue, white, and yellow cultivation benches increased the concentration of photosynthetic pigments in *T. serratifolia* seedlings, which increased total chlorophyll by 55%, 103% and 51%, respectively.

Key words: Colored cultivation benches, reflected photosynthetically active radiation, reflective material, seedling quality.

INTRODUCTION

Protected environments provide improved early development and growth for producing forest species seedlings (Costa et al., 2020a; Silva et al., 2021). These environments typically involve structures covered with screens or plastic films that shield the plants by reducing direct sunlight, rainfall, and the impact of biotic factors such as pathogens and predators (Cruz et al., 2016; Santos et al., 2017; Costa et al., 2020b). Such protected environment characteristics can result in higher-quality seedlings and greater vigor (Silva et al., 2020; Souza et al., 2022).

Another strategy to enhance forest seedling production is to use cultivation benches covered with reflective materials. This approach aims to increase the availability of light energy by using surfaces that reflect photosynthetically active radiation (PAR), thereby enhancing the photosynthetic process (Costa et al., 2021). In protected environments, using reflective materials on cultivation benches is intended to redirect PAR toward

the leaves, allowing for more efficient use of light energy. This leads to increased energy absorption and higher photosynthetic rates. However, the efficiency of light absorption by plants is closely linked to the photosynthetic apparatus of each species (Costa et al., 2020b; Campos et al., 2023).

Numerous forest species have been assessed under controlled environments employing silver reflective materials on cultivation benches. The findings have shown promising potential for supplementary radiation through the enhanced reflection of PAR. In *Schizolobium amazonicum* seedlings, aluminized reflective material on cultivation benches inside a greenhouse covered with 42%/50% shade netting under plastic film positively affected seedling quality (Mortate et al., 2019). *Syzygium cumini* seedlings showed improved development when reflective material (aluminum foil) was used under 30% shade conditions (Salles et al., 2017).

However, the intensity and quality of solar radiation reaching the plants can significantly affect their development (Dutra et al., 2012). Therefore, selecting an appropriate protected environment and cultivation benches covered with reflective material may improve seedling quality. In this context, producing high-quality seedlings of *Licania tomentosa* (Benth.) Fritsch, *Syzygium cumini* (L.) Skeels, and *Tabebuia serratifolia* (Vahl) G. Nicholson is essential due to the diverse applications of these species. In the existing literature, no studies have been found investigating the use of colored reflective materials to promote growth and improve the quality of forest seedlings.

This study aimed to evaluate the growth and photosynthetic pigments of *Licania tomentosa*, *Syzygium cumini*, and *Tabebuia serratifolia* seedlings under different wavelengths generated by colored cultivation benches.

MATERIALS AND METHODS

The experiments with *Licania tomentosa* (Benth.) Fritsch, *Syzygium cumini* (L.) Skeels, and *Tabebuia serratifolia* (Vahl) G. Nicholson seedlings were conducted at the Mato Grosso do Sul State University (UEMS), Cassilândia Unit, from 25 October to 12 December 2023. The experimental site is located at 19°07'21" S, 51°43'15" W; 516 m a.s.l. (CASSILANDIA-A742 automatic weather station, Vaisala brand, model MAWS 30, Finland). *Licania tomentosa* was sown on 25 October and data collection occurred on 12 December 2023 (48 d). *Syzygium cumini* was sown on 15 December and data were collected on 12 March 2024 (88 d). *Tabebuia serratifolia* was sown on 12 December with data collection on 5 April 2024 (115 d).

The experiments were conducted in a greenhouse measuring 18 m in length, 8 m in width, and 4 m in height at the gutter, encompassing a total floor area of 144 m². The structure featured an arched design and was covered with a 150-micron low-density polyethylene (LDPE) film that provided light diffusion and anti-drip properties. Beneath the LDPE film, a movable aluminized thermal-reflective screen with 50% shade was installed.

Colored laminated reflective materials (Fórmica, São Paulo, São Paulo, Brazil), they are called laminated mulches, were assessed on cultivation benches, each reflecting different wavelengths, in a completely randomized design with five treatments and four replicates. The treatments were as follows: Control (T1) with no material on the cultivation bench surface; glossy white laminate (T2); glossy red laminate (T3); glossy blue laminate (T4); and glossy yellow laminate (T5). The colors and their respective wavelengths were generated using glossy reflective Fórmica surfaces. For *L. tomentosa*, dark blue laminate was used, while for *S. cumini* and *T. serratifolia*, light blue laminate was applied.

The cultivation benches measured 1.4 m in width, 3.5 m in length, and 0.8 m in height, with each reflective material covering an area of 1.03 m × 1.25 m (1.28 m²), where each replicate was 80 cm away from each other, so that there was no interference from one treatment to the other. The laminates were 308 cm long, 125 cm wide and 0.8 mm thick. According to the manufacturers, they are manufactured at high pressure, contain a surface protection film (overlay), contain 100% melamine resin, decorative veneer, special kraft, and phenolic resin.

Seedlings were grown in 1.0 L pots filled with Carolina Soil substrate (Carolina Soil, Carolina Soil Company, Santa Cruz do Sul, Rio Grande do Sul, Brazil). The black pots measure 10.5 cm in height, 9.5 cm in diameter at the bottom and 13.5 cm in diameter at the top.

Licania tomentosa and *S. cumini* were sown directly into the pots, whereas *T. serratifolia* was initially sown in polystyrene trays and transplanted into pots 45 d after sowing (DAS). For *S. cumini* and *T. serratifolia*, which have a longer growth cycle, the substrate was supplemented with slow-release fertilizer (FORTH, Cerquilho, São Paulo, Brazil) at a rate of 12 g per pot at sowing/transplanting and an additional 4 g at 40 DAS for *S. cumini*

and 85 DAS for *T. serratifolia*. Seedlings were irrigated twice a day, morning and afternoon, as needed, using micro-sprinklers.

At 48 DAS for *L. tomentosa*, 88 DAS for *S. cumini*, and 115 DAS for *T. serratifolia*, the following variables were collected: Plant height (PH, cm), stem diameter (SD, mm), number of leaves (NL), shoot DM (SDM, g), and root DM (RDM, g). Total DM (TDM, g), seedling height-to-shoot DM ratio (PH/SDM), and the Dickson quality index (DQI) were also calculated. Seedling height was measured using a graduated ruler from the base of the stem (collar) to the apex of the apical meristem. The stem diameter was measured at the base of the stem with a digital caliper. Dry matter was obtained by drying the plant material in a forced-air circulation oven at 65 °C for 72 h and then weighing it on an analytical precision scale.

Chlorophyll and carotenoid contents, as well as their respective ratios, were determined: Chlorophyll *a* (CLA) (µg L⁻¹), chlorophyll *b* (CLB) (µg L⁻¹), total chlorophyll (CLT) (µg L⁻¹), carotenoids (CRT) (µg L⁻¹), CLA/CLB and CLT/CRT. Chlorophyll (*a* and *b*) and carotenoid extractions were performed according to the methodology described by Lichtenthaler (1987). A total of 0.5 g fresh plant material was weighed and mixed with 5 mL 80% acetone, then placed in 14 mL test tubes and stored in a refrigerator at 25 °C for 48 h. After this period, the tubes were centrifuged for 15 min at 4000 rpm. Subsequently, the supernatant was diluted from 0.3 mL extract to 1.7 mL 80% acetone. Absorbance measurements were taken using a spectrophotometer (IL-226-NM, Kasuaki, Tokyo, Japan) at wavelengths of 470, 647, 653, 663, and 665 nm.

Reflected photosynthetically active radiation (PAR) (µmol m⁻² s⁻¹) was monitored in each treatment (benches/tubes) using a portable digital pyranometer (Apogee Instruments, Logan, Utah, USA) daily at 09:30 h (local time) on clear days without clouds or haze. Air temperature (°C), relative humidity (%), and external and internal global radiation (W m⁻²) were recorded using an automatic weather station (E4000, Irriplus, Viçosa, Minas Gerais, Brazil) installed both inside the center of the greenhouse and outside. Readings were taken every 60 min (Table 1). External and internal global radiation measurements (W m⁻²) were collected from 10:00 to 17:00 h. The external (full sun) and internal PAR in the environment were collected with the sensor facing upwards and the reflected radiation by the benches the sensor was facing downwards. The internal incident radiation was measured and this was considered 100%. The reflected radiation of the colors was a percentage of the internal incident radiation, being obtained by the rule of three.

Table 1. Micrometeorological data of the internal and external environment and reflected PAR Radiation from treatments of the experiments with *Licania tomentosa*, *Syzygium cumini*, and *Tabebuia serratifolia* seedlings. *Licania tomentosa* was sown on 25 October and data collection occurred on 12 December 2023 (48 d). *Syzygium cumini* was sown on 15 December and data were collected on 12 March 2024 (88 d). *Tabebuia serratifolia* was sown on 12 December with data collection on 5 April 2024 (115 d). PAR: Photosynthetically active radiation.

Micrometeorological data	*Licania tomentosa*	*Syzygium cumini*	*Tabebuia serratifolia*
External temperature, °C	26.1	25.0	25.0
External relative humidity, %	71.8	82.3	80.6
External global radiation, W m⁻²	440.2	423.4	351.1
Internal temperature, °C	25.4	25.2	24.8
Internal relative humidity, %	76.3	69.0	59.2
Internal global radiation, W m⁻²	155.2	163.9	147.8
External PAR radiation, µmol m⁻² s⁻¹	1868.9	1918.3	1918.3
Internal PAR radiation, µmol m⁻² s⁻¹	484.7	490.4	490.4
Reflected PAR radiation – White, µmol m⁻² s⁻¹	172.0	236.9	236.9
Reflected PAR radiation – Yellow, µmol m⁻² s⁻¹	110.2	143.9	143.9
Reflected PAR radiation – Red, µmol m⁻² s⁻¹	51.4	127.1	127.1
Reflected PAR radiation – Blue, µmol m⁻² s⁻¹	18.7	72.6	72.6
Reflected PAR radiation – Control, µmol m⁻² s⁻¹	18.2	28.9	28.9

For *T. serratifolia*, additional variables were evaluated, including internal CO_2 concentration (C_i), transpiration rate (E), stomatal conductance (g_s), net CO_2 assimilation rate or net photosynthesis (A), water use efficiency (WUE), and instantaneous carboxylation efficiency (EiCi). To determine C_i, E, g_s, and A, measurements were taken at 09:00 h using a portable infrared gas exchange analyzer (LCi, ADC Bioscientific, Hertfordshire, UK). Subsequently, WUE was calculated as the ratio of net photosynthesis to transpiration, and EiCi as the ratio of net photosynthesis to internal CO_2 concentration.

Statistical analysis was performed using Sisvar version 5.3 (Ferreira, 2011). Data were subjected to ANOVA, and when significant differences were detected, means were grouped using the Scott-Knott test at a 5% probability level.

A multivariate analysis was performed using canonical variables (*Candisc* package). Data were also subjected to Pearson correlation analysis (*Corrplot* package), based on a correlation matrix with color gradients representing the relationships among the study variables. Positive correlations were highlighted in shades of blue, while negative correlations appeared in red. Correlations were marked with one asterisk for a 0.05% error level, two asterisks for 0.01%, and three asterisks for 0.001%. All analyses were conducted using R software, version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Seedlings of *L. tomentosa* grown on the blue, white, and yellow cultivation benches were 20%, 26%, and 19% taller than those on the control bench, respectively (Figure 1A). The number of leaves in plants from the white and yellow cultivation benches was 23% and 19% higher, respectively, compared to the control (Figure 1B). The stem diameter of plants on the yellow bench was 23% greater than that of the control (Figure 1C). The height-to-shoot DM ratio of *L. tomentosa* seedlings did not differ among treatments (Figure 1D). The SDM of seedlings on the blue, white, and yellow cultivation benches was 32%, 37%, and 25% higher than the control (Figure 1E). The RDM of seedlings on the white cultivation bench was 28% greater than that of the control (Figure 1F). The TDM of seedlings on the blue, white, and yellow cultivation benches was 26%, 35%, and 22% higher, respectively, compared to the control (Figure 1G). Seedling quality, as indicated by the Dickson quality index, was 16% and 21% higher for those on the white and yellow cultivation benches, respectively, relative to the control (Figure 1H).

Photosynthetic pigment levels in *L. tomentosa* seedlings were highest in plants cultivated on the control bench (Figures 2A-2D). Among the colored treatments, seedlings grown on the red and white benches exhibited higher total chlorophyll and carotenoid contents than those grown on the blue and yellow benches (Figures 2C and 2D). Chlorophyll *a* content was highest in seedlings from the red bench (Figure 2A). The chlorophyll *a/b* and total chlorophyll/carotenoid ratios did not differ significantly among treatments (Figures 2E and 2F).

The canonical variable analysis (Figure 3A) showed that treatments using dark blue, white, and yellow reflective benches had a stronger association with the growth of *L. tomentosa* seedlings. The Pearson correlation plot (Figure 3B) revealed a relationship between RDM, number of leaves (NL), and TDM, indicating that increased root system growth promotes a higher number of leaves and greater accumulation of TDM in *L. tomentosa* seedlings.

Seedlings of *S. cumini* grown on the yellow cultivation bench exhibited the greatest height, 15% taller than those on the control bench (Figure 4A). The NL (Figure 4B) and stem diameter (Figure 4C) did not differ significantly among treatments. The height-to-shoot DM ratio of *S. cumini* seedlings was highest in the white cultivation bench treatment (Figure 4D). The SDM was 35% and 15% greater in seedlings from the yellow and blue cultivation benches, respectively, compared to the control (Figure 4E). The RDM in seedlings from the yellow cultivation bench was 24% higher than in the control (Figure 4F). The TDM was 31% and 11% greater in seedlings from the yellow and blue benches, respectively, compared to the control (Figure 4G). Seedling quality, as indicated by the Dickson quality index, was 22% and 14% higher for the yellow and blue cultivation benches, respectively, compared to the control (Figure 4H).
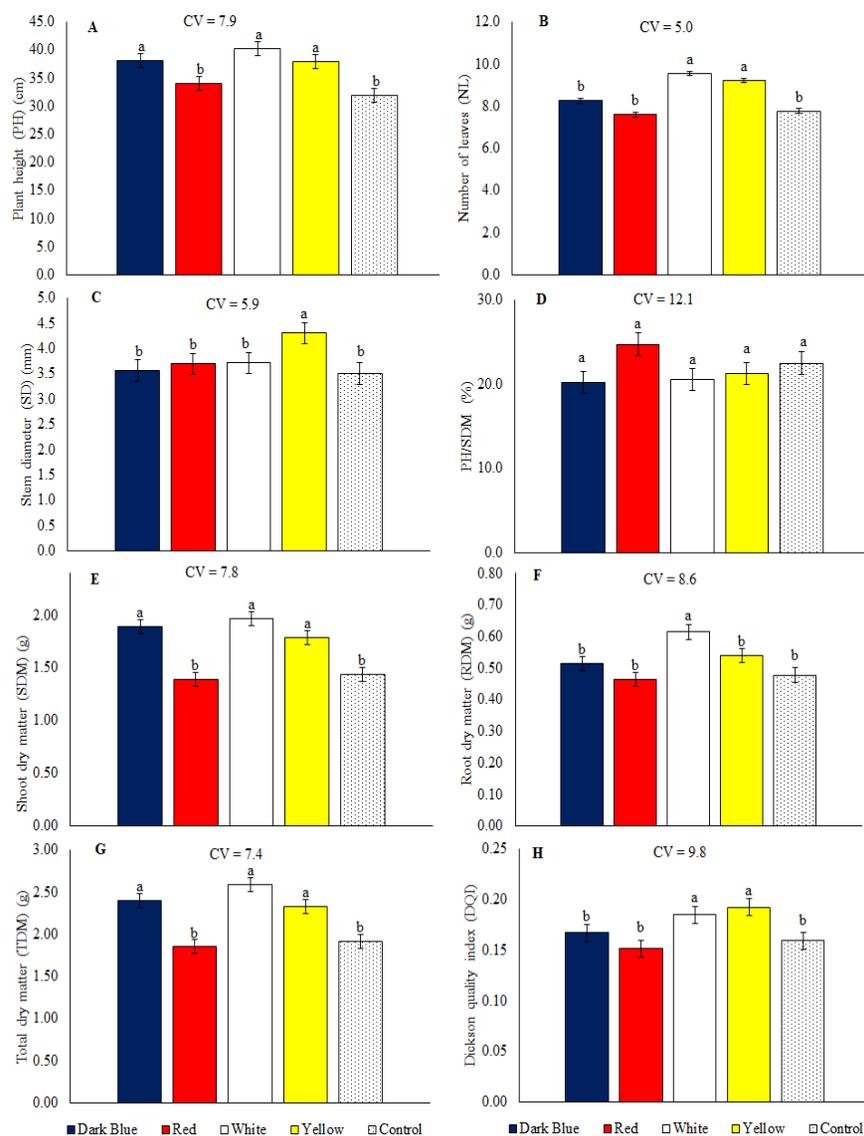
Figure 1. Seedling height (A), number of leaves (B), stem diameter (C), height-to-shoot DM ratio (D), shoot DM (E), root DM (F), total DM (G), and Dickson quality index (H) of *Licania tomentosa* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.
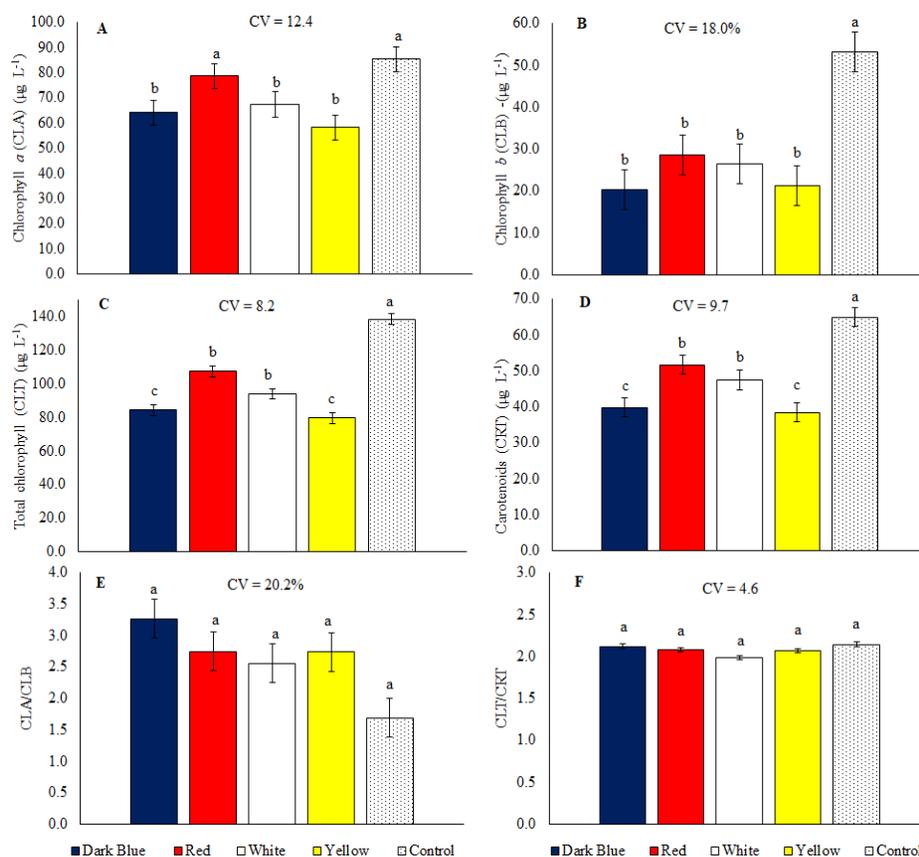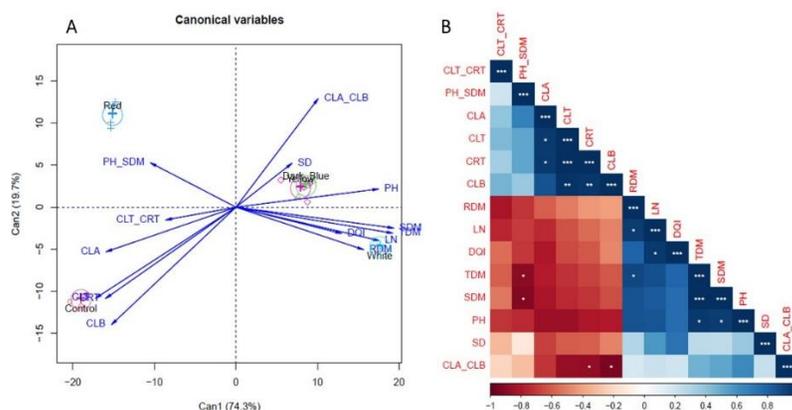
Figure 2. Chlorophyll *a* (A), chlorophyll *b* (B), total chlorophyll (C), carotenoids (D), chlorophyll *a/b* ratio (E), and total chlorophyll/carotenoid ratio (F) in *Licania tomentosa* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

Figure 3. Canonical variable analysis (A) and Pearson correlation (B) for plant height (PH), stem diameter (SD), number of leaves (NL), shoot DM (SDM), root DM (RDM), total DM (TDM), seedling height-to-shoot DM ratio (PH_SDM), Dickson quality index (DQI), chlorophyll *a* (CLA), chlorophyll *b* (CLB), total chlorophyll (CLT), carotenoids (CRT), chlorophyll *a/b* ratio (CLA_CLB), and total chlorophyll/carotenoid ratio (CLT_CRT) in *Licania tomentosa* seedlings.
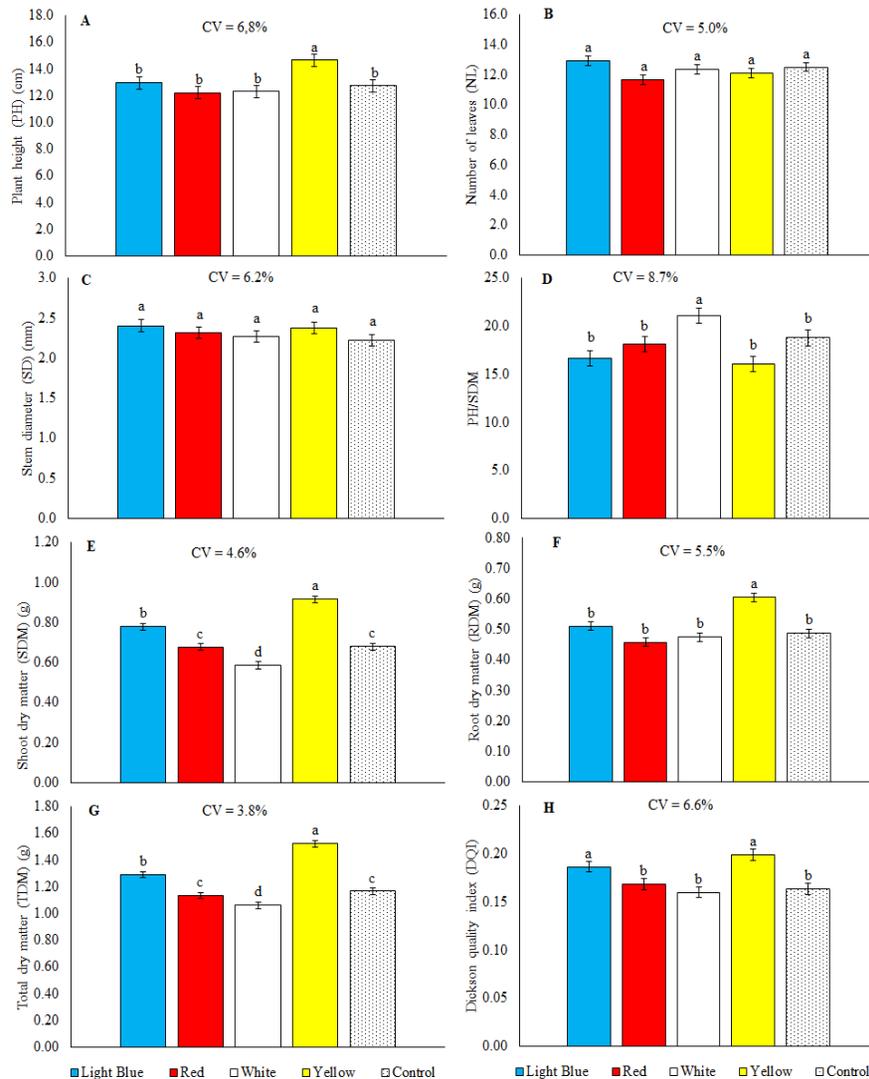
Figure 4. Seedling height (A), number of leaves (B), stem diameter (C), height-to-shoot DM ratio (D), shoot DM (E), root DM (F), total DM (G), and Dickson quality index (H) in *Syzygium cumini* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

Chlorophyll *a* (Figure 5A), chlorophyll *b* (Figure 5B), total chlorophyll (Figure 5C), and the total chlorophyll/carotenoid ratio (Figure 5F) in *S. cumini* plants were higher in seedlings grown on the control and yellow cultivation benches. However, chlorophyll *b* levels did not differ significantly from those in plants on the red bench (Figure 5B). Carotenoid content (Figure 5D) and the chlorophyll *a/b* ratio (Figure 5E) did not vary across treatments. Although the colored cultivation benches did not enhance photosynthetic pigments in *S. cumini* seedlings compared to the control, the yellow cultivation bench stood out among the color treatments.
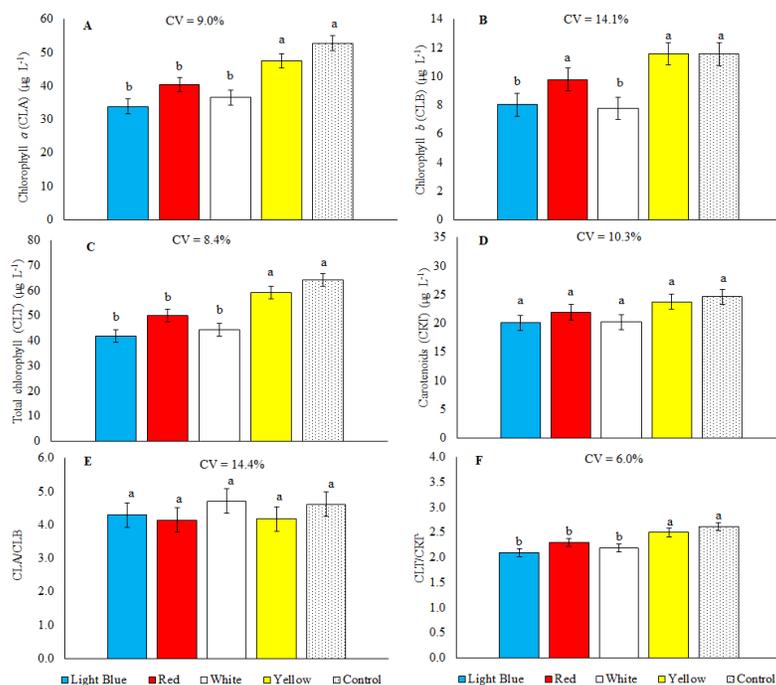
Figure 5. Chlorophyll *a* (A), chlorophyll *b* (B), total chlorophyll (C), carotenoids (D), chlorophyll *a/b* ratio (E), and total chlorophyll/carotenoid ratio (F) in *Syzygium cumini* seedlings as influenced by different wavelengths generated by colored benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

For the growth of *S. cumini* seedlings, canonical variable analysis (Figure 6A) showed that the yellow reflective bench treatment had the strongest association with seedling development. The Pearson correlation plot (Figure 6B) revealed a relationship between SDM, PH, RDM, and TDM, indicating that increases in SDM are correlated with increases in PH, RDM, and TDM.
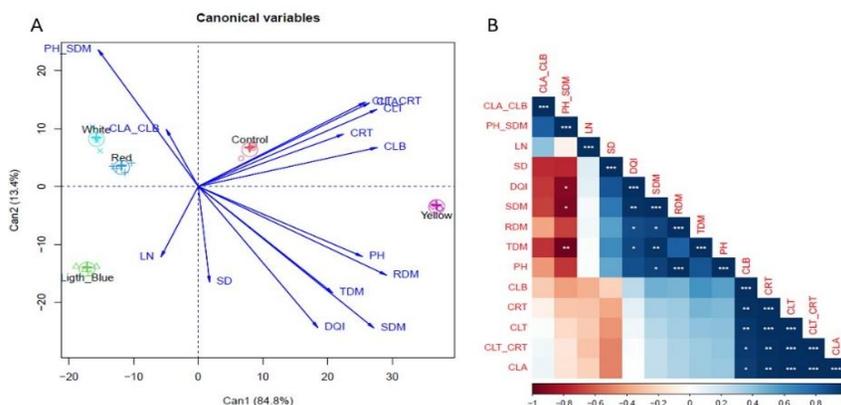

Figure 6. Canonical variable analysis (A) and Pearson correlation (B) for plant height (PH), stem diameter (SD), number of leaves (NL), shoot DM (SDM), root DM (RDM), total DM (TDM), seedling height-to-shoot DM ratio (PH_SDM), Dickson quality index (DQI), chlorophyll *a* (CLA), chlorophyll *b* (CLB), total chlorophyll (CLT), carotenoids (CRT), chlorophyll *a/b* ratio (CLA_CLB), and total chlorophyll/carotenoid ratio (CLT_CRT) in *Syzygium cumini* seedlings.

Seedlings of *T. serratifolia* grown on colored cultivation benches were larger than those on the control bench. Seedlings on the blue, red, white, and yellow cultivation benches were 26%, 37%, 54%, and 32% taller than the control (Figure 7A). The NL was 21%, 20%, and 14% higher in plants from the red, white, and yellow cultivation benches, respectively, compared to the control (Figure 7B). Stem diameter was 22%, 19%, 31%, and 20% greater in seedlings from the blue, red, white, and yellow cultivation benches, respectively, compared to the control (Figure 7C). The height-to-shoot DM ratio in *T. serratifolia* seedlings did not differ significantly among treatments (Figure 7D). The SDM was 35%, 39%, 63%, and 38% higher in seedlings from the blue, red, white, and yellow cultivation benches than in the control (Figure 7E). The RDM did not differ significantly among treatments (Figure 7F). The TDM was 24%, 32%, 50%, and 31% higher in seedlings from the blue, red, white, and yellow cultivation benches, respectively, compared to the control (Figure 7G). Seedling quality, as indicated by the Dickson quality index, was 11%, 15%, and 14% higher for seedlings grown on the red, white, and yellow cultivation benches, respectively, relative to the control (Figure 7H).
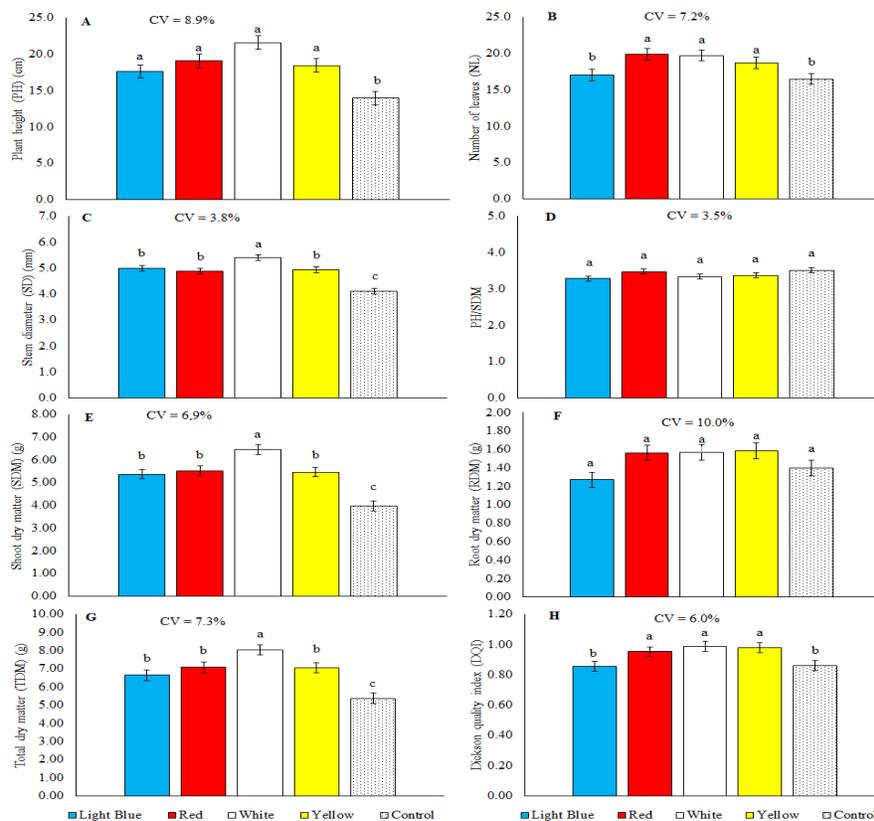

Figure 7. Seedling height (A), number of leaves (B), stem diameter (C), height-to-shoot DM ratio (D), shoot DM (E), root DM (F), total DM (G), and Dickson quality index (H) in *Tabebuia serratifolia* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

The colored treatments influenced and increased the levels of chlorophylls and carotenoids in *T. serratifolia* seedlings. Chlorophyll *a* content in seedlings from the blue, white, and yellow benches was 51%, 97%, and 48% higher than those from the control bench (Figure 8A). Chlorophyll *b* content in seedlings from the blue, red, white, and yellow benches was 68%, 89%, 122%, and 60% higher than in the control (Figure 8B). Total chlorophyll content in seedlings from the blue, red, white, and yellow benches was 55%, 33%, 103%, and 51% greater, respectively, compared to the control (Figure 8C). Carotenoid levels in seedlings from the blue, red,

white, and yellow cultivation benches were 140%, 52%, 170%, and 115% higher than in the control (Figure 8D). Seedlings grown on the red bench exhibited the lowest chlorophyll *a/b* ratio (Figure 8E), while those on the control bench showed the highest total chlorophyll/carotenoid ratio (Figure 8F). The colored treatments enhanced the photosynthetic pigments in *T. serratifolia* seedlings compared to the control, highlighting the influence of wavelength on these parameters in this species.
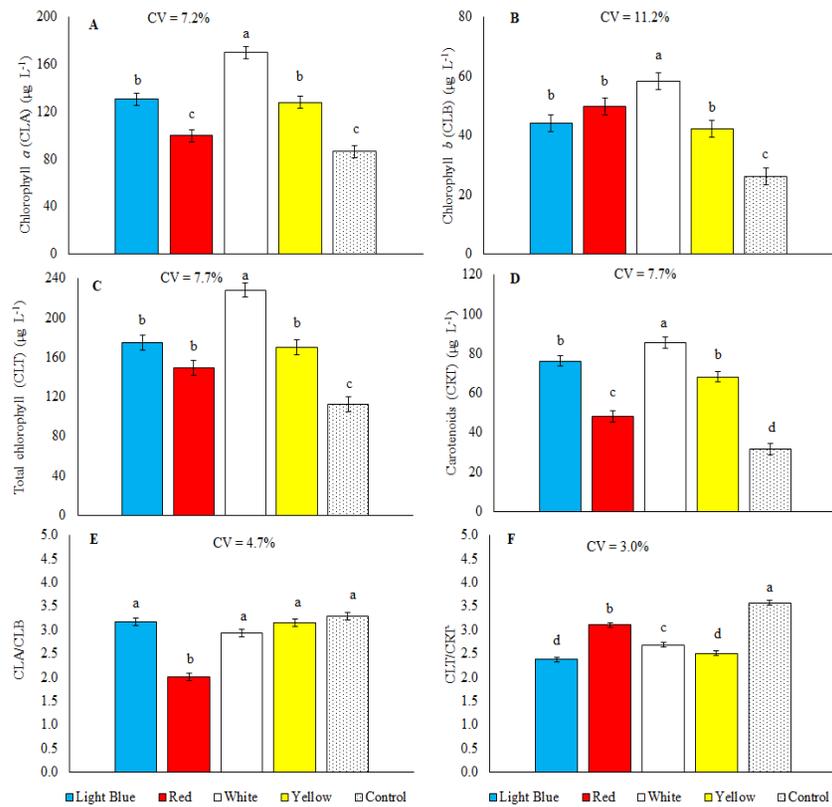

Figure 8. Chlorophyll *a* (A), chlorophyll *b* (B), total chlorophyll (C), carotenoids (D), chlorophyll *a/b* ratio (E), and total chlorophyll/carotenoid ratio (F) in *Tabebuia serratifolia* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

Canonical variable analysis (Figure 9A) showed that the treatments using white and yellow reflective cultivation benches had the strongest association with the growth of *T. serratifolia* seedlings. The Pearson correlation plot (Figure 9B) revealed, in general, a relationship between chlorophyll content (total and *b*) and certain growth parameters (TDM, SDM, SD) of *T. serratifolia* seedlings.
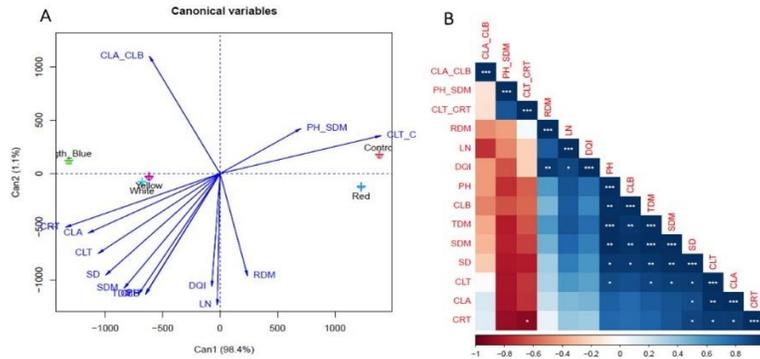
Figure 9. Canonical variable analysis (A) and Pearson correlation (B) for plant height (PH), stem diameter (SD), number of leaves (NL), shoot DM (SDM), root DM (RDM), total DM (TDM), seedling height-to-shoot DM ratio (PH_SDM), Dickson quality index (DQI), chlorophyll *a* (CLA), chlorophyll *b* (CLB), total chlorophyll (CLT), carotenoids (CRT), chlorophyll *a/b* ratio (CLA_CLB), and total chlorophyll/carotenoid ratio (CLT_CRT) in *Tabebuia serratifolia* seedlings.

Internal CO_2 concentration (Figure 10A) and stomatal conductance (Figure 10C) in *T. serratifolia* seedlings did not differ significantly among treatments. Transpiration rates in seedlings grown on the blue, red, white, and yellow cultivation benches were 35%, 24%, 19%, and 14% lower, respectively, compared to the control (Figure 10B). The CO_2 assimilation rates in seedlings from the blue and white benches were 41% and 33% higher than in the control (Figure 10D). Water use efficiency (WUE) in seedlings from the blue, red, and white cultivation benches was 115%, 56%, and 66% higher than in the control (Figure 10E). Instantaneous carboxylation efficiency in seedlings from the blue, red, and white cultivation benches was 38%, 10%, and 34% higher than in the control (Figure 10F).
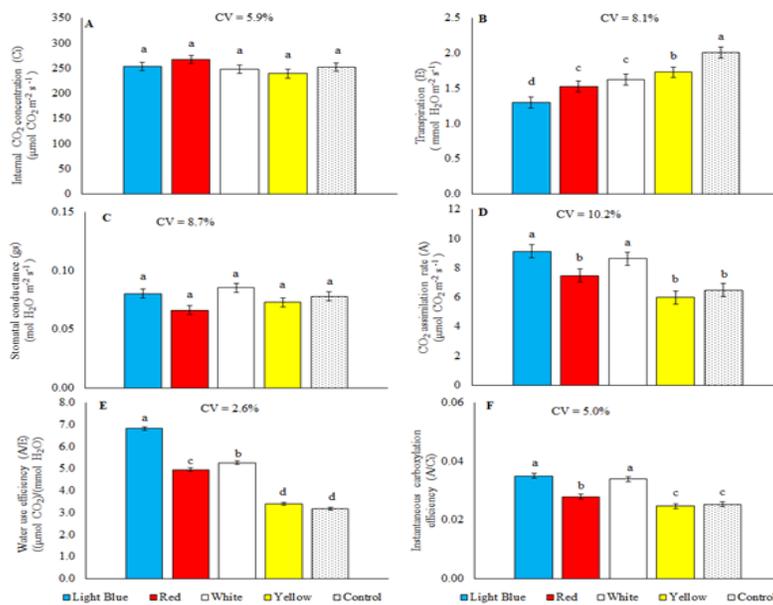

Figure 10. Internal CO_2 concentration (A), transpiration (B), stomatal conductance (C), CO_2 assimilation rate (D), water use efficiency (E), and instantaneous carboxylation efficiency (F) in *Tabebuia serratifolia* seedlings as influenced by different wavelengths generated by colored cultivation benches. CV: Coefficient of variation. Means followed by the same letter within each variable are grouped according to the Scott-Knott test at the 5% probability level. Vertical bars represent the standard error.

DISCUSSION

The use of cultivation benches with different colors of reflective materials alters the wavelengths of sunlight reflected toward the seedlings, leading to changes in photosynthetically active radiation (PAR) (Araújo et al., 2024) and, consequently, modifications in the morphological traits (Adibian et al., 2023; Davarzani et al., 2023) and photosynthetic pigments of *Licania tomentosa*, *Syzygium cumini*, and *Tabebuia serratifolia*. The use of reflective materials on cultivation benches enhances light utilization by redirecting ambient radiation to the abaxial surface of the leaves (Cavalcante et al., 2024).

Licania tomentosa
White and/or yellow reflective materials resulted in greater growth, dry biomass accumulation, and higher Dickson quality index values in *L. tomentosa* seedlings. White reflective material enhances seedling growth because white light consists of various spectra, including a small amount of green light, allowing deeper light penetration into the photosynthetic system (Lazzarini et al., 2017). Using reflective material also led to higher-quality seedlings with more robust root systems in rubber tree rootstock production (Costa et al., 2021).

Using reflectors that emit red or blue light can be particularly beneficial, as chlorophylls absorb these specific wavelengths from the visible spectrum more efficiently during the photosynthetic process (Taiz et al., 2017). Our findings indicate that seedlings exhibited higher chlorophyll concentrations when red reflective material was used. Comparable results were observed by Campos et al. (2023) in a study with tomato seedlings, and Araújo et al. (2024) in a study with baby-leaf chicory.

Although red light alone generates relatively less energy at the center of the photosynthetic reaction, its addition is beneficial in environments that already receive natural sunlight (Mascoli et al., 2020). The supplementation of red light specifically enhances photosystem II activity within the photosynthetic process, promoting more efficient reoxidation and, consequently, faster turnover of reaction centers and improved photon utilization (Zhen and van Iersel, 2017).

Syzygium cumini
Seedling height, shoot and root DM, and overall seedling quality responded to light quality, with the yellow cultivation bench having a notable influence on seedling development. The use of reflective material on cultivation benches led to an increase in leaf number and stem diameter. The light reflected from the colored benches toward the leaves enhances light energy availability, promoting the development of a greater number of leaves in *S. cumini* (Dantas et al., 2025) and improving its photosynthetic efficiency.

Our study demonstrated that the concentration of photosynthetic pigments increased due to the yellow reflective material used on the cultivation benches, leading to taller plants. This effect is attributed to the reflective material's ability to redirect part of the PAR from the cultivation benches back toward the leaves, supplying wavelengths that effectively activate photosynthetic pigments. This activation provides an adequate amount of light energy, which is essential for photophosphorylation and the production of ATP and $NADPH_2$, key components required for the next stage of photosynthesis, ultimately leading to the generation of photoassimilates that contribute to pigment formation (Taiz et al., 2017; Costa et al., 2021).

In an experiment with *Capsicum chinense* Jacq. (Bortolheiro et al., 2025), photosynthetic pigment levels also increased in response to the use of yellow reflective material. Although yellow wavelengths have minimal influence on the absorption or excitation of photosynthetic pigments, the amount of available light was sufficient to meet the energy requirements of *S. cumini*.

Tabebuia serratifolia
Using colored cultivation benches is an alternative method that provides seedlings with favorable conditions for capturing PAR, resulting in enhanced growth (Araújo et al., 2024). Colored reflective materials are designed to improve light reflectance and the absorption rates that generate byproducts essential for photosynthesis (Taiz et al., 2017). The observed increase in growth parameters such as stem diameter, shoot DM, and total biomass in *T. serratifolia* seedlings under white, red, or yellow reflective materials may be associated with light intensity and quality (Bao et al., 2024).

Chlorophyll and carotenoid concentrations in plants grown with the white reflective material enhanced the photosynthetic process. This suggests that PAR was more efficiently utilized by the plant photosynthetic system, leading to increased chlorophyll concentrations and improved plant growth. Both photomorphogenesis and photosynthesis in plants are influenced by light wavelength, photoperiod, and intensity through photoreceptors that regulate plant development (Bilodeau et al., 2019).

Seedlings grown with the blue reflective material exhibited higher water use efficiency and lower transpiration rates. It is worth noting that seedlings exposed to the white and blue reflective materials showed higher photosynthetic rates and stomatal conductance. Similar results were reported in baby leaf kale seedlings (Dantas et al., 2025).

This study demonstrated that using reflective materials on cultivation benches provides favorable conditions for capturing PAR, resulting in the successful development of *L. tomentosa*, *S. cumini*, and *T. serratifolia* seedlings.

CONCLUSIONS

The colors, through their distinct wavelengths, positively influenced the growth and quality of *Licania tomentosa*, *Syzygium cumini*, and *Tabebuia serratifolia* seedlings, as well as the photosynthetic pigment levels in *T. serratifolia*. To produce *L. tomentosa* seedlings with high biometric quality, blue, white, and yellow cultivation benches can be used, especially white and yellow.

The different wavelengths generated by the colored cultivation benches did not enhance the photosynthetic pigment content in *L. tomentosa* and *S. cumini* seedlings. Yellow cultivation benches should be used to produce *S. cumini* seedlings with high biometric quality, followed by blue benches.

To produce *T. serratifolia* seedlings with high biometric quality, colored cultivation benches can be used, especially red, white, and yellow benches. The different wavelengths generated by the colored cultivation benches enhanced the photosynthetic pigment content in *T. serratifolia* seedlings, especially under blue, white, and yellow cultivation benches.

We can increase resource use efficiency in plant environments by harnessing incident irradiance within the cultivation space using reflective materials (cultivation benches) of different colors. These materials enhance the amount of photosynthetically active radiation reaching the plants, offering an energy-efficient and cost-effective alternative to supplemental lighting with LEDs.

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