International Journal of Horticultural Science and Technology (2027) Vol. 14, No. 1, pp. 157-170 doi.org/10.22059/10.22059/ijhst………………….

International Journal of Horticultural Science and Technology
Journal homepage: https://ijhst.ut.ac.ir

Different Wavelengths Promoted by Colored Growth Benches in the Production of Tamarind Seedlings

Alana Silva Rocha[1], Thaise Dantas[2], Fernanda Pacheco de Almeida Prado Bortolheiro[1], Edilson Costa[1]*, Abimael Gomes da Silva[1], Flávio Ferreira da Silva Binotti[1], Giovana Pinheiro Viana da Silva[1], Gustavo Haralampidou da Costa Vieira[1], Eduardo Pradi Vendruscolo[1]

1 Department of Agronomy, University of State of Mato Grosso do Sul, Cassilândia, Mato Grosso do Sul, Brazil
2 Department of Agronomy, Federal University of Grande Dourados, Dourados, Mato Grosso do Sul, Brazil

*Corresponding author's email: edilson.costa@uems.br

ARTICLE INFO

Article history:

Received: 6 May 2025,
Received in revised form: 30 June 2025,
Accepted: 6 July 2025,

Article type:

Research paper

Keywords:

Light supplementation,
Photosynthetic pigments,
Reflected photosynthetically active radiation,
Tamarindus indica L.

ABSTRACT

This study aimed to evaluate the growth and photosynthetic pigment content of tamarind seedlings in response to different wavelengths generated by colored growth benches in various protected environments. The experiment was carried out in two protected environments: (i) an agricultural greenhouse covered with low-density polyethylene film and an aluminized thermal-reflective net (Aluminet®), providing 50% shading beneath the film; and (ii) a roofed structure enclosed at a 45° angle with black monofilament fabric, also providing 50% shading. Within each environment, a completely randomized design was adopted with five treatments and four replications: T1 – control (bench surface without covering); T2 – bench covered with glossy white laminate; T3 – bench covered with glossy red laminate; T4 – bench covered with glossy blue laminate; and T5 – bench covered with glossy yellow laminate. The colored laminates (Fórmicas®), with glossy reflective surfaces, enhanced specific wavelengths, with the bright white laminate providing the highest reflectance. The yellow reflective bench promoted greater growth of tamarind seedlings across environments. Meanwhile, yellow, blue, and red reflective benches increased the concentration of photosynthetic pigments in seedlings grown under protected conditions. Overall, the results demonstrate that different wavelengths promoted by colored benches can positively influence the quality of tamarind seedlings, with the laminates playing a key role in both growth and pigment production.

Introduction

The tamarind tree (*Tamarindus indica* L.), a member of the Fabaceae family, is native to equatorial Africa, India, and Southeast Asia, and it thrives in tropical and subtropical climates (Balasubramanian et al., 2018). In the Brazilian Cerrado, it is a species of great importance because its deep and extensive root system allows it to withstand prolonged droughts. Beyond its ecological resilience, the species has a wide range of uses: its fruits are consumed in cooking, oil can be extracted from its seeds, its byproducts are used for animal feed, and its wood also has economic value (Chimsah et al., 2020).

The production of high-quality tamarind seedlings requires protected environments, since the availability and quality of light strongly influence plant development (Silva et al., 2023; Kang et al., 2023). Excessively high light intensities, particularly in summer, can hinder plantation success. For this reason, protected environments are commonly used to reduce light intensity during periods of excessive radiation (Eskandarzade et al., 2023). Shading reduces the amount of light reaching the plant surface, thereby affecting growth and development. However, both the quantity of light (photoperiod and intensity) and its quality (spectral composition) play

---

critical roles in plant physiology and growth (Yao et al., 2017; Loi et al., 2021).

One approach to improving conditions in shaded environments is to enhance the use of solar radiation, particularly photosynthetic active radiation (PAR). This portion of the solar spectrum, ranging from 400 to 700 nm, is indispensable for photosynthesis—the only biological process capable of producing carbon compounds, especially sugars, which are fundamental to plant growth and development (Taiz et al., 2014).

The use of growth benches lined with reflective material is a recent methodology in plant production. Its purpose is to redirect part of the photosynthetic active radiation (PAR) toward the abaxial side of leaves, thereby increasing the total amount of light available and enhancing photosynthetic efficiency (Campos et al., 2023). Research has shown that combining protected environments with reflective benches yields promising results for the cultivation of both horticultural and forestry species.

Within this context, however, few studies have investigated the effects of different wavelengths generated by colored benches on plant growth and photosynthetic pigments, particularly in tamarind trees. Based on this gap, the present study was guided by the following hypotheses: (i) benches covered with white reflective material increase PAR; (ii) benches covered with blue and red reflective material enhance the photosynthetic pigment content of tamarind seedlings; and (iii) seedlings grown on white reflective benches exhibit greater plant height and a higher number of leaves.

Accordingly, this study aimed to evaluate the growth and photosynthetic pigments of tamarind seedlings in response to different wavelengths promoted by colored benches under distinct protected environments.

Materials and Methods

Location and characteristics of the experimental area

Experiments with tamarind seedlings (*Tamarindus indica* L.) were carried out at the State University of Mato Grosso do Sul, University Unit of Cassilândia, MS, in two protected environments between October 20, 2022, and January 9, 2023. The study site is located at a latitude of -19.1225° (19º07'21" S), a longitude of -51.7208° (51°43'15" W), and an altitude of 516 m (CASSILÂNDIA A742 automatic station). The region has an average annual rainfall of 1507 mm (CLIMATE-DATA.ORG, 2025).

The experiments were conducted in two distinct protected environments (Fig. 1). Environment 1 consisted of an arched agricultural greenhouse measuring 18.0 m in length, 8.0 m in width, and 4.0 m in height, with a total floor area of 144 m^2. It was covered with 150-micron low-density polyethylene (LDPE) light-diffusing film, and beneath this film, a 50% shading aluminized thermo-reflective mobile screen was installed (Fig. 1A). Environment 2 consisted of an agricultural shed measuring 18.0 m in length, 8.0 m in width, and 3.5 m in height, also with a floor area of 144 m^2. This structure was covered and enclosed at 45° with a black monofilament screen providing 50% shading (Fig. 1B).

Fig. 1. Protected environments. (**A**) greenhouse; (**B**) screenhouse.

Experimental design

In each protected environment, colored laminated reflective materials (Fórmicas®) were tested on the growth benches in a completely randomized design, with five treatments and four replications (Fig. 2): T1: control, with no material on the bench surface; T2: bench covered with glossy white laminate; T3: bench covered with glossy red laminate; T4: bench covered with glossy blue laminate, and T5: bench covered with glossy yellow laminate. Reflective glossy Formica® promoted the colors of the countertops.

Experimental conduct and data collection

The benches used in the experiment measured 1.40 m in width, 3.50 m in length, and 0.80 m in height. Each reflective material covered an area of 1.0 m × 1.2 m (1.20 m²). Seedlings were grown in 1.0 L pots filled with Carolina Soil® substrate. Three seeds were sown per pot, and after emergence, thinning was carried out using scissors, leaving one plant per pot. Irrigation was performed twice daily, in the morning and afternoon, when necessary.

At 65 days after sowing (DAS), the following growth parameters were evaluated: plant height (PH, cm), collar diameter (CD, mm), number of leaves (NL), shoot dry matter (STDM, g), and root system dry matter (TSDM, g). From these measurements, total dry matter (TDM, g), the ratio of seedling height to collar diameter (RHD), and the Dickson quality index (DQI) were calculated. Plant height was measured with a graduated ruler from the plant collar to the apex of the apical meristem, while collar diameter was measured with a digital caliper. Dry matter was obtained after drying samples in a forced-air circulation oven at 65 °C for 72 h and then weighing them on a precision analytical balance.

Photosynthetic pigments (chlorophylls and carotenoids) and their ratios were also determined. The following variables were measured: chlorophyll a (CLA, µg L^{-1}), chlorophyll b (CLB, µg L^{-1}), total chlorophyll (CLT, µg L^{-1}), carotenoids (CRT, µg L^{-1}), the CLA/CLB ratio, and the CLT/CRT ratio. Chlorophylls (a and b) and carotenoids were extracted following Lichtenthaler (1987). For this, 0.5 g of fresh plant material was weighed, and 5 mL of 80% acetone was added. Samples were stored in 14 mL test tubes at 25 °C for 48 h under refrigeration. After this period, the tubes were centrifuged for 15 min at 4,000 rpm, and the supernatant was diluted at a ratio of 0.3 mL extract to 1.7 mL of 80% acetone. Absorbance readings were taken with a spectrophotometer at wavelengths of 470 nm, 647 nm, 653 nm, 663 nm, and 665 nm.

The reflected PAR (µmol m^{-2} s^{-1}) from the growth benches was monitored daily at 9:30 a.m. (MS) using a portable digital pyranometer (Apogee®) (Dantas et al., 2025). PAR data were analyzed in a randomized block design with six replications every 10 days. External PAR (full sun) was 1975.2 µmol m^{-2} s^{-1}, while internal PAR values were 571 µmol m^{-2} s^{-1} (28.9% of external PAR) and 709.7 µmol m^{-2} s^{-1} (35.9% of external PAR).

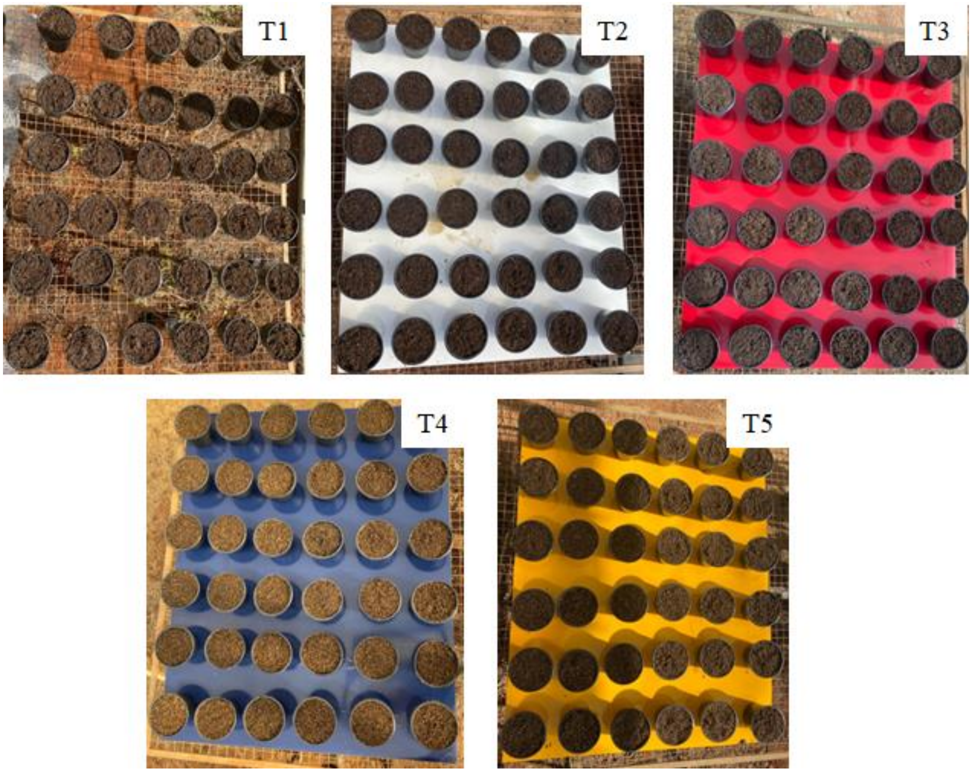

Fig. 2. Colored laminated reflective materials (Fórmicas®). T1: control, with no material on the bench surface; T2: bench covered with glossy white laminate; T3: bench covered with glossy red laminate; T4: bench covered with glossy blue laminate, and T5: bench covered with glossy yellow laminate.

Statistical analysis

Statistical analyses were performed using the Sisvar 5.3 program (Ferreira, 2014), and treatment means were compared using the LSD test at a 5% probability level. Multivariate analyses included canonical variable analysis (Candisc package) and principal component analysis (PCA) with the Ggfortify and Factoextra packages. Data were also subjected to Pearson's correlation analysis (Corrplot package), using a correlation matrix with color gradients to represent the relationships among study variables. Positive correlations were highlighted in shades of blue, whereas negative correlations were highlighted in red. Statistical significance was indicated as $p < 0.05$, $p < 0.01$, and $p < 0.001$. The abbreviations used in the analysis were G = greenhouse and S = screenhouse. All analyses were conducted in R software version 4.3.3 (R Core Team, 2024).

Results

Reflected PAR

Micrometeorological data were collected on reflected PAR and on the percentage of internal photosynthetically active radiation reflected by the benches in the growing environments. In both the greenhouse and the screenhouse, the bench covered with white laminate reflected the greatest amount of PAR. The yellow bench showed the second-highest reflection (Fig. 3A and B).

The PAR on the greenhouse benches showed that the white and yellow benches were 673 and 423% higher than the control, respectively. On the screen, it was 641 and 404%, respectively (Fig. 3A and B).

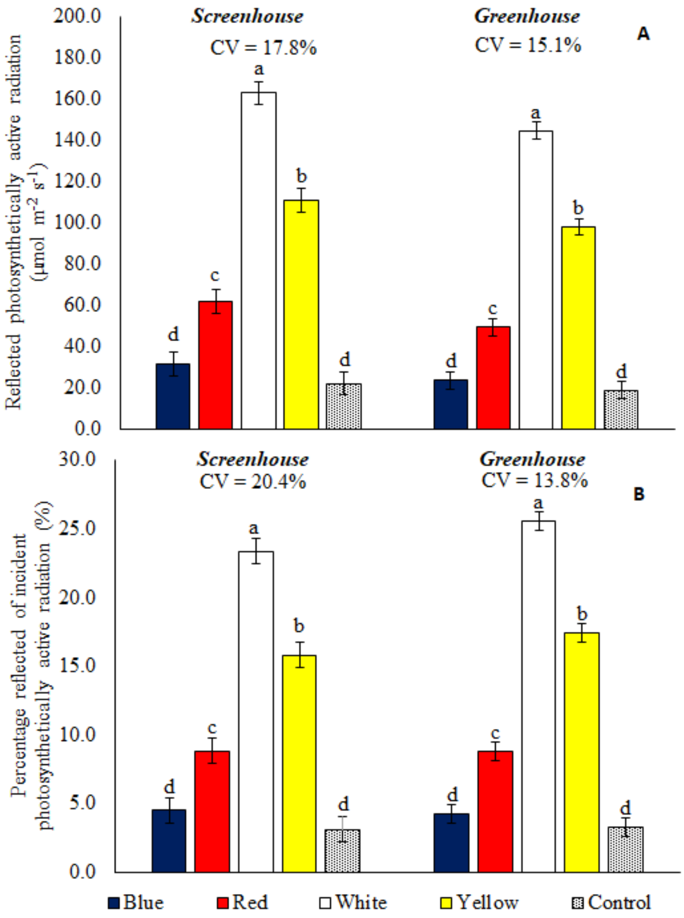

Fig. 3. (**A**) PAR reflected (µmol m^{-2} s^{-1}) by the growth benches; and (**B**) percentage of internal PAR reflected by the growth benches during the production of tamarind seedlings. CV = coefficient of variation. Averages followed by the same letter do not differ by the LSD test. Vertical bars indicate the standard error.

Growth parameters

Using the yellow laminate in both environments, the screen and the greenhouse (Fig. 4A) resulted in taller plants than the other reflective benches and the control. The seedlings from the yellow bench were 21.6% taller in the greenhouse and 10.2% taller in the screen than the control.

The tamarind seedlings produced a higher number of leaves when grown on the yellow laminate in both environments (Fig. 4B). In the greenhouse, seedlings on the yellow bench had 27.6% more leaves than the control, while in the screenhouse they had 24.1% more.

In the greenhouse, the use of yellow laminate benches also promoted a larger collar diameter compared to the other treatments. Seedlings grown on the blue and yellow laminate benches showed the largest collar diameters (Fig. 4C). In this environment, seedlings on the yellow laminate had diameters 14.7% greater than the control, while those on the blue laminate had diameters 14.0% greater. In the screenhouse, seedlings grown on yellow laminate benches had diameters 11.0% greater than the control.

The highest height-to-diameter ratios in the greenhouse were observed in seedlings grown on yellow, red, and control benches, with values of 6.52, 6.42, and 6.55, respectively. Among these, the yellow laminate benches produced the highest ratio, which was 6.0% greater than the control (Fig. 4D).

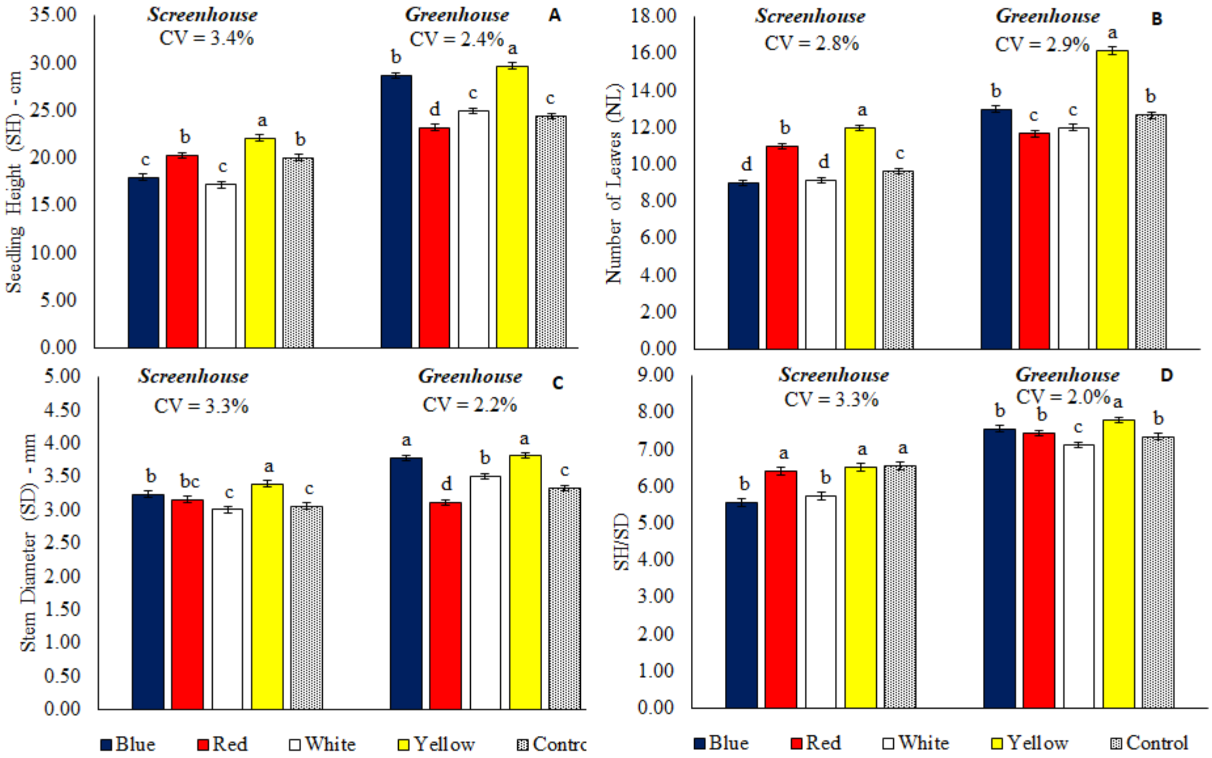

Fig. 4. (**A**) Seedling height; (**B**) number of leaves; (**C**) stem diameter; and (**D**) seedling height/stem diameter ratio of tamarind seedlings according to the different wavelengths promoted by the colored growth benches. CV = coefficient of variation. Means followed by the same letter do not differ by the LSD test. Vertical bars indicate the standard error.

In the greenhouse, the seedlings from the bench coated with yellow laminate had the highest shoot dry matter compared to the other treatment groups, with plants 35.4% larger than those from the control. In the greenhouse, the benches coated with blue, white, and yellow laminates had seedlings with the highest shoot dry matter, with values of 2.72, 2.62, and 2.50 g, respectively (Fig. 5A).

For root dry matter, no differences were observed among seedlings grown on yellow, red, and control benches in the greenhouse, with values of 0.69, 0.68, and 0.64 g, respectively. In this environment, seedlings grown on yellow laminate benches showed the highest root dry matter, representing a 23.8% increase compared to the control (Fig. 5B).

In the screenhouse, seedlings grown on yellow laminate benches exhibited the highest total dry matter, which was 27.1% greater than the control. In the greenhouse, seedlings grown on yellow, blue, and white laminates did not differ statistically, with values of 3.40, 3.34, and 3.13 g, respectively (Fig. 5C). Using yellow laminate on the growth bench in both environments, screenhouse and greenhouse, resulted in a higher Dickson Quality Index (DQI) than the other growth benches, 19.1% higher than the control bench in both environments.

Photosynthetic pigments

In both environments, the chlorophyll *a* content of the tamarind seedlings was not influenced by the growth benches. In the screenhouse, the seedlings from the control (55.7 µg L^{-1}) and yellow (55.6 µg L^{-1}) growth benches were numerically higher than those from the other treatments. In the greenhouse, the yellow and blue growth benches exhibited seedlings with numerically higher chlorophyll values than the other treatments, at 67.5 µg L^{-1} and 65.8 µg L^{-1}, respectively (Fig. 6A).

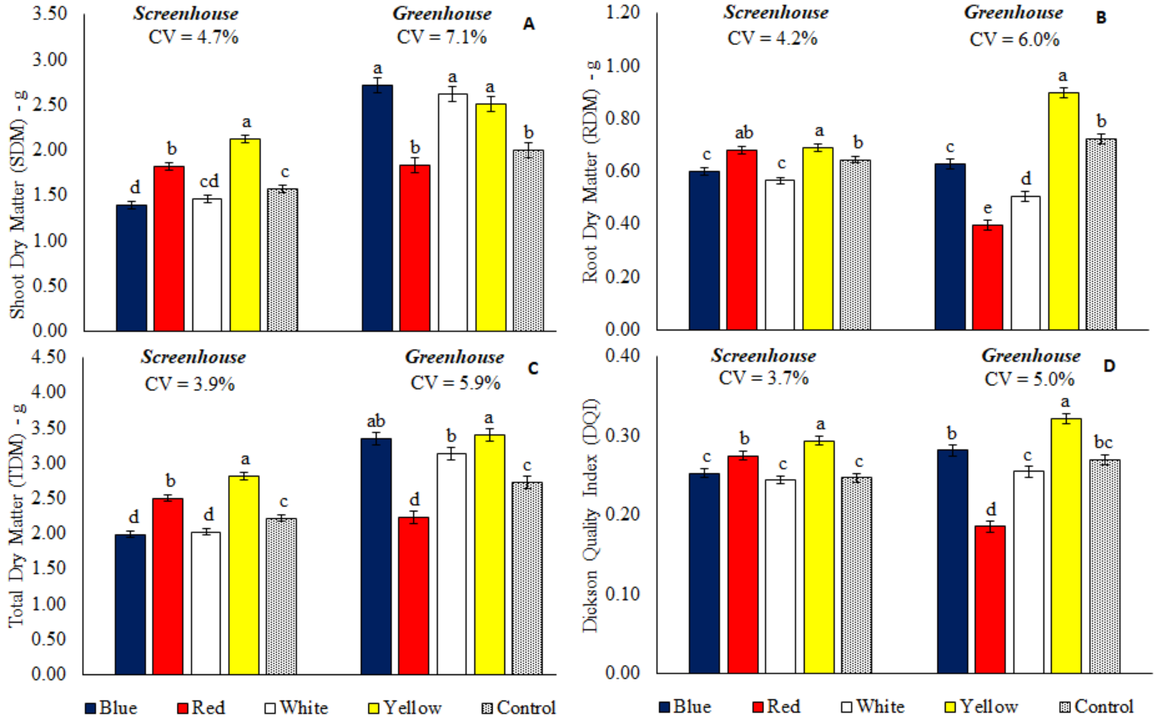

Fig. 5. (**A**) Shoot dry matter; (**B**) root dry matter; (**C**) total dry matter; and (**D**) Dickson Quality Index of tamarind seedlings according to the different wavelengths promoted by the colored growth benches. CV = coefficient of variation. Means followed by the same letter do not differ by the LSD test. Vertical bars indicate the standard error.

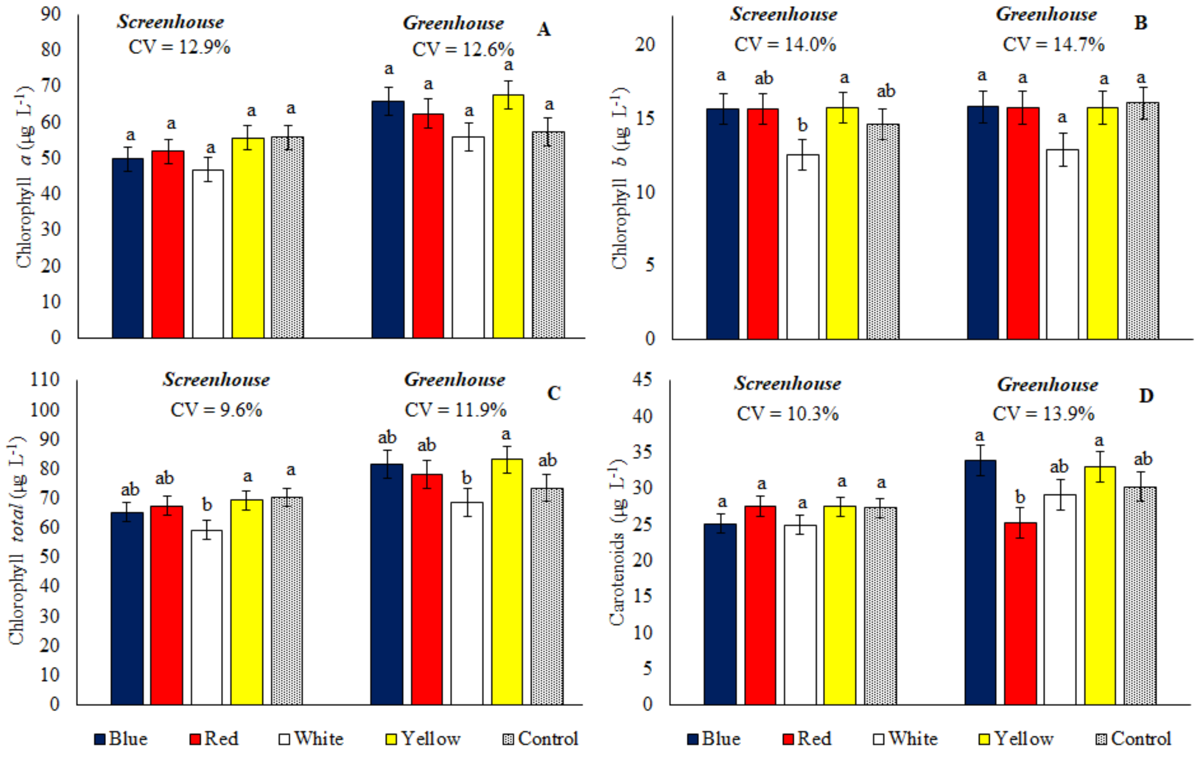

Fig. 6. (**A**) Chlorophyll *a*; (**B**) chlorophyll *b*; (**C**) total chlorophyll; and (**D**) carotenoids of tamarind seedlings according to the different wavelengths promoted by the colored growth benches. CV = coefficient of variation. Means followed by the same letter do not differ by the LSD test. Vertical bars indicate the standard error.

In the screenhouse, the chlorophyll *b* content of the seedlings was numerically higher with the yellow and blue laminates on the growth benches, with values of 15.71 and 15.66 µg L^{-1}. In the greenhouse, the chlorophyll *b* content of the plants was not influenced by the growth benches. However, the chlorophyll *b* content of the plants from the control and blue growth benches was numerically higher, with 16.0 µg L^{-1} and 15.8 µg L^{-1} (Fig. 6B).

In the screenhouse, the yellow laminate and control benches produced the highest total chlorophyll content in tamarind seedlings. In the greenhouse, seedlings grown on the yellow laminate benches had the greatest total chlorophyll content (Fig. 6C).

Carotenoid content in the screenhouse was not affected by the use of laminates. In the greenhouse, however, seedlings grown on blue and yellow laminate benches had higher carotenoid levels (Fig. 6D).

The use of laminates did not influence the chlorophyll a/b ratio in either environment. In the screenhouse, seedlings from the control and white benches showed the highest numerical values, with 3.86 µg L^{-1} and 3.73 µg L^{-1}, respectively. In the greenhouse, seedlings grown on yellow and white benches had the highest numerical values, with 4.37 µg L^{-1} and 4.36 µg L^{-1}, respectively (Fig. 7A).

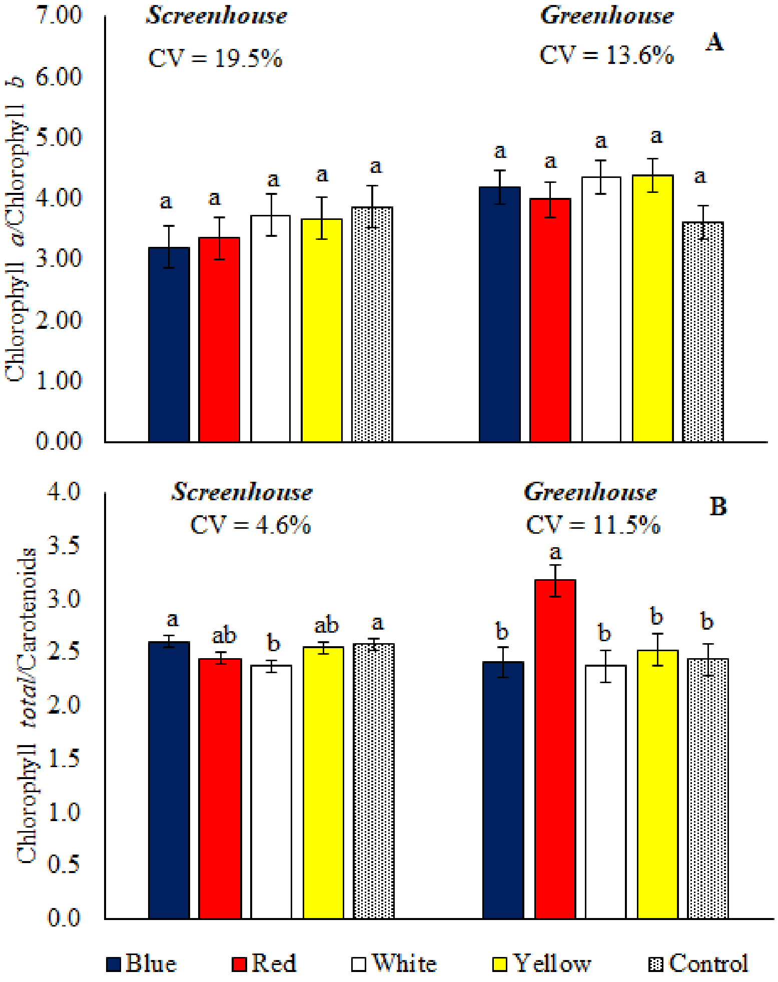

Fig. 7. (**A**) Chlorophyll *a*/*b* ratio; and (**B**) total chlorophyll/carotenoid ratio of tamarind seedlings according to the different wavelengths promoted by the colored growth benches. CV = coefficient of variation. Means followed by the same letter do not differ by the LSD test. Vertical bars indicate the standard error.

The seedlings from the blue and control growth benches exhibited the highest total chlorophyll to carotenoid ratio in the screenhouse. In contrast, the red laminate resulted in the highest total chlorophyll to carotenoid ratio in the greenhouse, which was 30.2% greater than that of the plants in the control growth benches. This is illustrated in Figure 7B, showing the highest total chlorophyll to carotenoid ratio among the plants.

Multivariate analysis

The principal component analysis (Fig. 8) revealed the formation of two clusters, representing groups of similar environments. The first cluster included G_Dark Blue, G_Yellow, G_White, G_Control, and S_Yellow. The second cluster included S_Dark Blue, S_Yellow, S_White, S_Red, S_White, and G_Red. Cluster 1 showed stronger relationships with growth and photosynthetic pigment parameters. This indicates that these environments promote the greatest growth and pigment production in tamarind seedlings. A positive correlation was observed between carotenoid content (CRT) and plant height (PH). As seedling height increased, carotenoid content also increased.

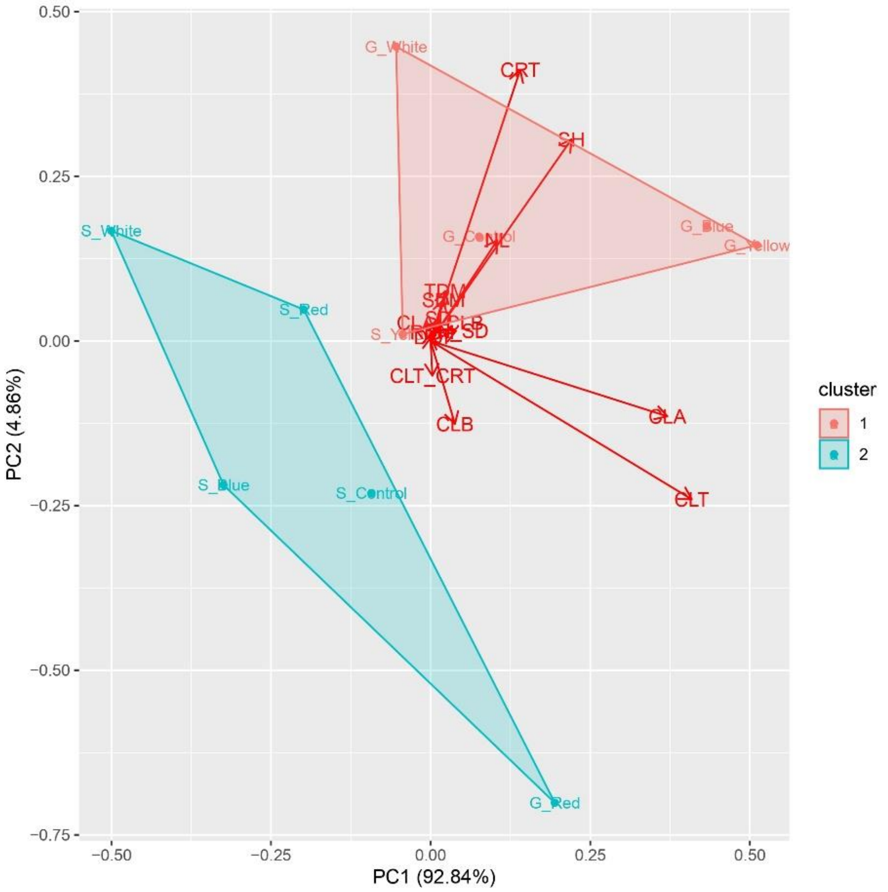

Fig. 8. Principal component analysis of the variables seedling height (SH), stem diameter (SD), number of leaves (NL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), seedling height/stem diameter ratio (SH_SD), Dickson quality index (DQI), Chlorophyll *a* (CLA). Chlorophyll *b* (CLB), Total chlorophyll (CLT), Carotenoids (CRT), Chlorophyll *a*/*b* ratio (CLA_CLB), and Total Chlorophyll/Carotenoids ratio (CLT_CRT). G = greenhouse; S = screenhouse.

The analysis of canonical variables (Fig. 9) showed that the yellow growth bench in the greenhouse was the closest to the vectors root system dry matter (RDM) and Dickson quality index (DQI), proving that this treatment provides better quality seedlings, as also shown in Figure 5B and D. For photosynthetic pigment, it was found that both the greenhouse treatment with dark blue and yellow benches had a strong relationship with the chlorophyll and carotenoid contents of the seedlings, showing seedlings with higher photosynthetic pigment levels.

Pearson's correlation (Fig. 10) revealed positive relationships between growth and photosynthetic pigment variables. The Dickson Quality Index (DQI) showed a positive correlation with stem diameter (SD), root dry matter (RDM), total dry matter (TDM), and carotenoids (CRT). Conversely, DQI was negatively correlated with the total chlorophyll/carotenoids ratio (CLT/CRT). These results indicate that an increase in leaf carotenoid content contributes to higher seedling quality according to the Dickson Quality Index.

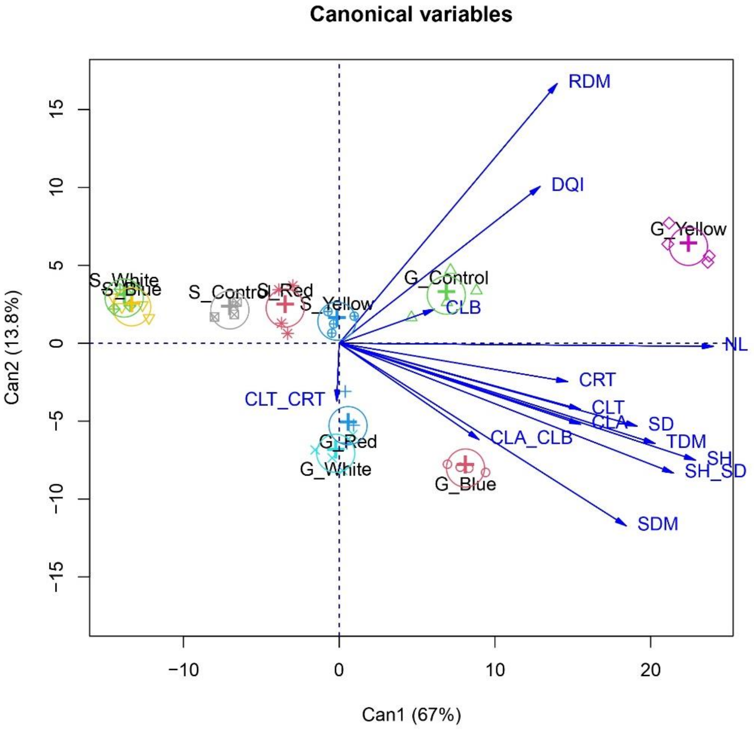

Fig. 9. Analysis of canonical variables for seedling height (SH), stem diameter (SD), number of leaves (NL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), seedling height/stem diameter ratio (SH_SD), Dickson quality index (DQI), Chlorophyll *a* (CLA). Chlorophyll *b* (CLB), Total Chlorophyll (CLT), Carotenoids (CRT), Chlorophyll *a*/*b* ratio (CLA_CLB), and Total chlorophyll/carotenoids ratio (CLT_CRT). G = greenhouse; S = screenhouse.

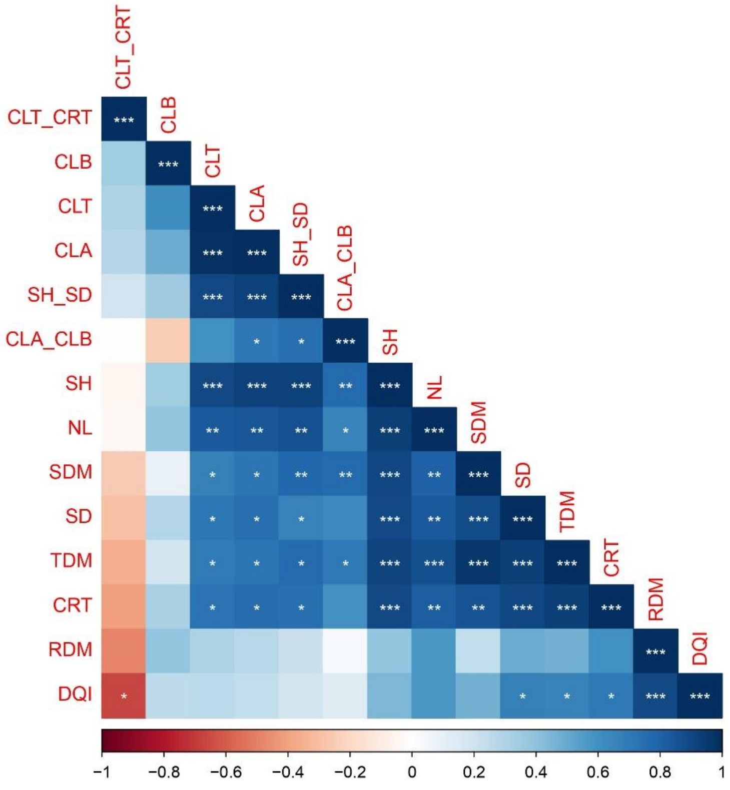

Fig. 10. Pearson's correlation for seedling height (SH), stem diameter (SD), number of leaves (NL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), seedling height/stem diameter ratio (SH_SD), Dickson quality index (DQI), Chlorophyll *a* (CLA). Chlorophyll *b* (CLB), Total Chlorophyll (CLT), Carotenoids (CRT), Chlorophyll *a*/*b* ratio (CLA_CLB), and Total Chlorophyll/Carotenoids ratio (CLT_CRT).

Discussion

The results of this study confirm the first and second hypotheses: white reflective material increases PAR, and growth benches covered with blue and red reflective material enhance the photosynthetic pigment content of plants. However, the findings diverge from the third hypothesis, as tamarind trees exhibited greater plant height and a higher number of leaves when grown on yellow reflective material. The incidence of PAR represents a micrometeorological factor that strongly influences plant growth in protected environments (Costa et al., 2021). Within such environments, growth benches of different colors reflect specific wavelengths of sunlight toward the cultivated plants, thereby altering PAR and leading to changes in photosynthetic pigments, morphological traits, and overall seedling quality (Ilic et al., 2022; Abidian et al., 2023; Davarzani et al., 2023).

This study demonstrated that growth benches covered with white reflective material produced higher PAR in both environments, consistent with results reported for cherry tomato seedlings (Campos et al., 2023). More favorable environmental conditions were observed for jambolan seedlings in shaded environments. Furthermore, the use of reflective materials improved the distribution of solar energy among plants, thereby supporting enhanced development (Salles et al., 2017).

The yellow reflective material, in particular, influenced plant height, number of leaves, collar diameter, and the seedling height-to-stem diameter ratio of tamarind seedlings. Reflectance from the cultivation bench increased the availability of PAR, which directly stimulated growth (Costa et al., 2021). Similarly, light supplementation in sweet bell pepper seedlings was found to increase plant height, dry biomass, and stem diameter (Abidian et al., 2023).

In terms of growing environments, tamarind seedlings cultivated in greenhouses displayed greater height, number of leaves, collar diameter, and seedling height-to-stem diameter ratio compared with those grown in shaded conditions. Under shaded environments, plants tend to expand their leaf area, producing a greater number of leaves to optimize light capture (Taiz et al., 2014).

The yellow laminate on the growth benches promoted greater dry biomass, a response directly linked to the availability of light energy, which drives photosynthesis and, consequently, biomass production (Tewolde et al., 2018). Among the variables used to assess seedling performance, the Dickson Quality Index stands out as a crucial parameter, being more reliable than height alone (Silva et al., 2020; Matos et al., 2020). Another highly important trait is root dry matter. In this study, seedlings grown on benches with yellow laminate, across both environments, exhibited the highest root dry matter. This finding indicates an allocation of resources toward the development of more robust root systems, a hallmark of hardy plants that are better adapted and more resilient than those with finer roots and lower root mass (Alves et al., 2023). Robust root systems also enhance nutrient uptake, thereby promoting overall growth.

Excessive light, however, can degrade chlorophyll and lead to reduced chlorophyll content (Lima et al., 2017). A decline in chlorophyll compromises photosynthesis, which in turn slows seedling development. In our research, seedlings grown on benches with white laminate displayed decreased stem diameter, reduced leaf number, lower dry biomass, and diminished DQI. Pearson’s correlation analysis (Figure 10) further revealed that higher ratios of total chlorophyll to carotenoids (CLT/CRT) were associated with lower DQI values.

Chlorophylls and carotenoids, the principal photosynthetic pigments in plants, play essential roles in physiological processes such as photo-oxidation, light capture, and plant coloration, while also contributing nutritional value as precursors of vital vitamins and antioxidants (Klem et al., 2019). The synthesis of these pigments is particularly regulated by light spectra (Taiz et al., 2014). These findings emphasize the decisive role of light quality in shaping phytochemical concentrations in plants (Naznin et al., 2019; Moradi et al., 2021).

Chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, the chlorophyll a/b ratio, and the total chlorophyll/carotenoid ratio were higher in plants grown on benches with blue, red, and yellow laminates (Araújo et al., 2024). Blue light is particularly influential in regulating stomatal opening, photosynthesis, and chlorophyll production (Wang et al., 2016; Miao et al., 2016; Zheng et al., 2019). For instance, a significant increase in chlorophyll a and total chlorophyll content was observed in amaranth under blue light (Toscano et al., 2021). Similarly, light supplementation using LED lamps that combined red and blue intensities enhanced photosynthetic activity in parsley (Litvin et al., 2020).

The reflected wavelengths from the cultivation benches were effective in activating the photosynthetic pigments of photosystems I and II, such as chlorophylls and carotenoids. These pigments provided the energy necessary for photophosphorylation, leading to the generation of ATP and $NADPH_2$—molecules essential for subsequent stages of photosynthesis (Taiz et al., 2017). As a result, photoassimilates were produced, contributing to dry mass accumulation. In addition, reflection from the colored benches increased the availability of light energy, thereby stimulating the growth of tamarind seedlings.

The influence of bench color on growth parameters and seedling quality was directly associated with the type of protected environment in which production occurred. Based on the results of this study, it can be concluded that the different wavelengths promoted by colored laminates yielded promising outcomes, demonstrating clear effects on both seedling growth and the production of photosynthetic pigments.

With respect to growing environments, the greenhouse generally produced plants with superior development compared with the screenhouse, although the difference was not statistically significant. Notably, the combination of a greenhouse environment with yellow reflective material resulted in the greatest accumulation of dry phytomass, as well as a more extensive distribution of dry phytomass within the root system (Fig. 5). This treatment also produced the highest Dickson Quality Index (Figs. 5 and 9) and demonstrated the strongest relationship between growth parameters and photosynthetic pigment production (Fig. 8).

Conclusion

The use of benches covered with yellow reflective laminate promoted greater seedling growth, an increased number of leaves, and larger collar diameter in tamarind seedlings across cultivation environments. Additionally, yellow, blue, and red laminates enhanced the concentration of photosynthetic pigments in tamarind seedlings grown under protected conditions, thereby improving seedling quality through higher phytomass accumulation and superior quality index values. Based on these findings, the use of yellow reflective laminates on cultivation benches in protected environments (greenhouses) with at least 50% shading is recommended for the production of high-quality tamarind seedlings.

Acknowledgments
The authors thank the Foundation for Supporting the Development of Education, Science, and Technology of the State of Mato Grosso do Sul (FUNDECT), the National Council for Scientific and Technological Development (CNPq), and the Coordination for the Improvement of Higher Education Personnel (CAPES).

Author Contributions

ASR, EC, TD, FFSB, and AGS contributed to conceptualization; ASR, EC, EPV, TD, GPVS, and FPAPB contributed to investigation; EC, ASR, FFSB, and GHCV contributed to methodology; GHCV, EC, FFSB, and EPV contributed to project administration; EC, FPAPB, and FFSB contributed to supervision; EC, FFSB, AGS, GPVS, and FPAPB contributed to formal analysis; and ASR, EC, AGS, TD, GPVS, EPV, and FPAPB contributed to writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Conflict of Interest

The authors indicate no conflict of interest in this work.

References

Adibian M, Hamidoghli Y, Aliniaeifard S. 2023. Effect of Supplemental Light Quality and Season on Growth and Photosynthesis of Two Cultivars of Greenhouse Sweet Pepper (*Capsicum annuum* L.). International Journal of Horticultural Science and Technology 10, (Special Issue: Light in Horticulture) 51-66. http://doi.org/10.22059/ijhst.2023.353706.609.

Alves VCD, Silva AG, Costa E, Dantas T, Binotti FFS, Martins MB, Vendruscolo EP, Vieira GHC. 2023. Influence of Different Protected Environments and Reflector Material on Cultivated Oiti (*Licania tomentosa* [Benth.] Fritsch) Seedlings. Arboriculture & Urban Forestry (AUF) 49(4), 159-169. https://doi.org/10.48044/jauf.2023.015.

Araújo TAN, Costa E, Dantas T, Binotti FFS, Vendruscolo EP, Vieira GHC, Ribeiro FCS, Lima SM, Andrade LHC. 2024. Growth and bioactive compounds of baby-leaf chicory on colored cultivation benches with different wavelengths. Chilean Journal of Agricultural Research 84(5), 653-662. https://oes.chileanjar.cl/files/CJAR240116-84-5-2024.pdf

Balasubramanian A, Sudha P, Prasath CH, Sangareswari M, Radhakrishnan S, Suresh KK. 2018. Tamarind science and technology. Scientific Publishers 133p.

Campos RSD, Costa E, Cavalcante DF, Freitas RA, Binotti FFDS. 2023. Ornamental cherry tomatoes in different protected environments and reflector materials in cultivation Bench. Revista Caatinga 36, 09-20.

https://doi.org/10.1590/1983-21252023v36n102rc.

Chimsah F A, Nyarko G, Abubakari AH. 2020. A review of explored uses and study of nutritional potential of tamarind (*Tamarindus indica* L.) in Northern Ghana. African Journal of Food Science 14(9), 285-294. https://doi.org/10.5897/AJFS2018.1744.

Climate-Data.Org. Climate-Data.org > América do Sul > Brasil > Mato Grosso do Sul > Cassilândia. 2025. Available at: http://pt.climate-data.org/location/43419/. Accessed on June 20, 2025.

Costa E, Da Silva BL, Aguiar FK, Pereira TC, Binotti FFD. 2021. Use of benches with reflective material to favor production of rubber tree rootstock seedlings. Engenharia Agrícola. 41: 409-417. https://doi.org/10.1590/1809-4430-Eng.Agric.v41n4p409-417/2021.

Dantas T, Costa E, Scalon SPQ, Araújo TAN, Binotti FFS, Vendruscolo EP, Vieira GHC, Martins MB, Lima SM, Andrade LHC (2025). Colored Benches Increase Growth, Photosynthetic Pigments, and Gas Exchange in Baby Leaf Kale. International Journal of Horticultural Science and Technology 12, 343-354. https://doi.org/10.22059/ijhst.2024.372574.776

Davarzani M, Aliniaeifard S, Mehrjerdi MZ, Roozban MR, Saeedi SA, Gruda NS. 2023. Optimizing supplemental light spectrum improves growth and yield of cut roses. Scientific Reports 1391, 21381. https://doi.org/10.1038/s41598-023-48266-3.

Eskandarzade P, Mehrjerdi ZM, Didaran F, Gruda NS, Aliniaeifard S. 2023. Shading Level and Harvest Time Affect the Photosynthetic and Physiological Properties of Basil Varieties. Agronomy 13(10), 2478. https://doi.org/10.3390/agronomy13102478.

Ferreira DF. Sisvar: 2014.A Guide for its Bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia. 38(2), 109–12. https://doi.org/10.1590/S1413-70542014000200001

Ilić ZS, Milenković L, Šunić L, Fallik E. 2022. Shading net and grafting reduce losses by environmental stresses during vegetables production and storage. Biology and Life Sciences Forum 16(1), 27. https://doi.org/10.3390/IECHo2022-12506.

Kang JH, Yoon HI, Kim J, Ahn TI, Son JE. 2023. Ray-tracing analysis on the far-red induced light-capturing ability of kale. Scientia Horticulturae 311, 111806. https://doi.org/10.1016/j.scienta.2022.111806.

Klem K, Gargallo-Garriga A, Rattanapichai W, Oravec M, Holub P, Veselá B, Sardans J, Peñuelas J, Urban, O. 2019. Distinct morphological, physiological, and biochemical responses to light quality in barley leaves and roots. Frontiers in Plant Science 10, 1026. https://doi.org/10.3389/fpls.2019.01026.

Lichtenthaler HK. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. In: Packer L, Douce R. (Eds.). Methods in enzymology. 1987. Bad Honnef: Academic 148, 350-382. DOI: https://doi.org/10.1016/0076-6879(87)48036-1.

Lima VA, Pacheco FV, Avelar RP, Alvarenga IC, Pinto JEB, Alvarenga AAD. 2017. Growth, photosynthetic pigments and production of essential oil of long-pepper under different light conditions. Anais da Academia Brasileira de Ciências 89(2), 1167-1174. https://doi.org/10.1590/0001-3765201720150770.

Litvin AG, Currey CJ, Wilson LA. 2020. Effects of supplemental light source on basil, dill, and parsley growth, morphology, aroma, and flavor. Journal of the American Society for Horticultural Science 145(1), 18-29. https://doi.org/10.21273/JASHS04746-19.

Loi M, Villani A, Paciolla F, Mulè G, Paciolla C. 2021. Challenges and opportunities of light-emitting diode (LED) as key to modulate antioxidant compounds in plants. A review. Antioxidants 10(1), 42. https://doi.org/10.3390/antiox10010042

Matos AHP, Silva AG, Binotti FFS, Costa E, Binotti ED. 2020. C. Agentes químicos na produção de mudas de elevada qualidade de Schizolobium amazonicum. Research, Society and Development 9(8), e881986403. https://doi.org/10.33448/rsd-v9i8.6403.

Miao YX, Wang XZ, Gao LH, Chen QY, Qu M. 2016. Blue light is more essential than red light for maintaining the activities of photosystem II and I and photosynthetic electron transport capacity in cucumber leaves. Journal of Integrative Agriculture 15(1), 87-100. https://doi.org/10.1016/S2095-3119(15)61202-3

Moradi S, Kafi M, Aliniaeifard S, Salami SA, Shokrpour M, Pedersen C, Moosavi-Nezhad M, Wróbel J, Kalaji HM. 2021. Blue light improves photosynthetic performance and biomass partitioning toward harvestable organs in saffron (*Crocus sativus* L.). Cells 10(8), 1994. https://doi.org/10.3390/cells10081994.

Naznin MT, Lefsrud M, Gravel V, Azad MOK.

2019. Blue light added with red LEDs enhance growth characteristics, pigments content, and antioxidant capacity in lettuce, spinach, kale, basil, and sweet pepper in a controlled environment. Plants. 8(4): 93. https://doi.org/10.3390/plants8040093.

R Core Team. R: A language and environment for statistical computing (Versão 4.3.3). 2024. R Foundation for Statistical Computing. available at https://www.r-project.org Accessed on: June 24, 2024.

Salles JS, Lima AHF, Costa E. 2017. Mudas de jambolão sob níveis de sombreamento, bancadas refletoras e profundidade de semeadura. Revista de Agricultura Neotropical. 4(5): 110-118. https://doi.org/10.32404/rean.v4i5.2181

Silva JBM, Vendruscolo EP, Bastos FEA, Binotti FFS, Sant' Ana GR, Costa E. 2023. Does light supplementation improve the initial growth of hops seedlings in a protected environment? Revista de Agricultura Neotropical 10(3), e7401-e7401. https://doi.org/10.32404/rean.v10i3.7401.

Silva AG, Costa E, Pereira TCC, Binotti FFS, Scaloppi Júnior EJ, Zoz T. 2020. Quality of rubber tree rootstock seedlings grown in protected environments and alternative substrates. Acta Scientiarum Agronomy 42, e43469. http://doi.org/10.4025/actasciagron.v42i1.43469.

Taiz L, Zeiger E, Moller IM, Murphy A. 2014. Plant Physiology and Development. 6.ed. Sun-Derland: Sinauer Associates. 700p.

Tewolde FT, Shiina K, Maruo T, Takagaki M, Kozai T, Yamori W. 2018. Supplemental LED inter-lighting compensates for a shortage of light for plant growth and yield under the lack of sunshine. PLoS ONE 13(11), e0206592. https://doi.org/10.1371/journal.pone.0206592.

Toscano S, Cavallaro V, Ferrante A, Romano D, Patané C. 2021. Effects of different light spectra on final biomass production and nutritional quality of two microgreens. Plants 10(8), 1584. https://doi.org/10.3390/plants10081584.

Wang J, Lu W, Tong Y, Yang Q. 2016. Leaf morphology, photosynthetic performance, chlorophyll fluorescence, stomatal development of lettuce (*Lactuca sativa* L.) exposed to different ratios of red light to blue light. Frontiers in Plant Science 7, 250. https://doi.org/10.3389/fpls.2016.00250.

Yao H, Zhang Y, Yi X, Zuo W, Lei Z, Sui L, Zhang W. 2017. Characters in light-response curves of canopy photosynthetic use efficiency of light and N in responses to plant density in field-grown cotton. Field Crops Research 203, 192-200. https://doi.org/10.1016/j.fcr.2016.12.018.

Zheng L, He H, Song W. 2019. Application of light-emitting diodes and the effect of light quality on horticultural crops: A review. HortScience 54(10), 1656-1661. https://doi.org/10.21273/HORTSCI14109-19.