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Photosynthetic Pigments and Growth of Guaraci Cumari do Pará Pepper (*Capsicum chinense Jacq.*) Seedlings on Growth Benches with Different Color Wavelengths

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ABSTRACT

Quality seedlings can guarantee the establishment of a productive crop, and, at the same time, light quality makes it possible to increase photosynthetic pigments. This study evaluated plant pigments along with the growth of Guaraci Cumari do Pará ornamental pepper seedlings on different-colored benches that emitted specific wavelengths. The wavelengths appeared from different reflective colored laminates (reflective bright blue laminate, reflective bright red laminate, reflective bright white laminate, reflective bright yellow laminate, and a control treatment without reflective material) on growth benches considered as treatments. The treatments were in a completely randomized design with six replications. The white laminate increased the photosynthetic-active radiation inside the experimental environment by 16.6%. The blue laminate promoted quality in pepper seedlings similar to the control bench regarding growth parameters, such as seedling height, stem diameter, and dry matter. However, the seedlings in the control bench had a higher quality index. The wavelengths promoted by the blue, red, and yellow laminates increased the production of chlorophyll a (41, 49, and 44%), chlorophyll b (36, 34, and 31%), and total chlorophyll (39, 45, and 40%) in the Guaraci Cumari do Pará pepper seedlings compared to the control. The color of laminates on the cultivation benches reflected different levels of photosynthetic-active radiation, influencing the traits of photosynthetic pigments in the Guaraci Cumari do Pará pepper seedlings.

Introduction

Peppers belong to the Solanaceae family and the Capsicum genus. They have a spicy aroma and come in various colors and shapes. This genus can be grown in almost all Brazilian regions. Pepper production has grown over the years in Brazilian agribusiness (Costa et al., 2017). Peppers are grown in all Brazilian states and are a source of income in small farms. They can be used as an ornamental plant or eaten fresh or processed (Costa et al., 2017).

Seedling quality is essential for establishing crops in fields, providing acceptable survival rates after transplanting and good yields (Cabral et al., 2020). Various technologies can ensure better

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seedling development, such as using a experimental environment, shading levels, benches with reflective material, the type of material used to cover the environment, the time of year, and geographical location (Cabral et al., 2020). These technologies can alter the microclimate where farmers produce seedlings and pay particular attention to seedling quality. Another prime effect of technologies for cultivation in a experimental environment is protection against adverse weather conditions and biotic factors (Moreira et al., 2021).

Benches with reflective material intercept parts of the photosynthetic-active radiation (PAR). The benches redirect PAR to the plants, reaching parts that would otherwise miss light due to shading (Costa et al., 2021). Light incidence is essential for photosynthesis, but light quality and intensity can influence several morphophysiological parameters and their productivity (Davarzani et al., 2023). PAR can alter plant physiology, such as photosynthetic pigments and chloroplasts, leading to changes in morphology, such as growth, height, and diameter (Taiz et al., 2017).

Chloroplasts absorb radiation between blue and red wavelengths, which can affect photosynthesis (Li et al., 2020; Davarzani et al., 2023). There are reports of increased growth, dry matter mass, and plant height grown in red light (Yu et al., 2017; Abidian et al., 2023; Davarzani et al., 2023).

Variations in morphological characteristics, such as plant height, diameter, branching, chlorophyll content, and carotenoids, have received attention in several crops while using colored coverings in experimental environments (Ilic et al., 2022; Ilic and Fallic, 2017). Previous research has considered plants such as bromeliads (Holcman and Sentelhas, 2013), lettuce (*Lactuca sativa*) (Amaro de Sales et al., 2021), lavender (*Ocimum selloi*) (Costa et al., 2010), and long-pepper (*Piper hispidinervum*) (Lima et al., 2017), as well as covering the cultivation bench with colored reflective material for cherry tomatoes (Campos et al., 2023), basil (*Ocimum basilicum*) (Cavalcante et al., 2021), and arugula (*Eruca sativa*) (Cavalcante et al., 2023).

Using aluminized reflective material on growth benches increased seedling quality in papaya (*Carica papaya*) (Cabral et al., 2020), jambolan (*Syzygium cumini*) (Salles et al., 2017), paricá (*Schizolobium amazonicum*) (Mortate et al., 2019), baru (*Dipteryx alata*) (Costa et al., 2020a; Costa et al., 2020b). Also, biquinho pepper (*Capsicum chinense*) showed greater plant height, diameter, and leaf count during the initial development phase, resulting in higher fruit production (Moreira et al., 2021).

Using colored reflective material on cultivation benches is a recent technology in producing seedlings where the experimental environment can increase seedling quality. Therefore, this study evaluated the pigments and growth of Guaraci Cumari do Pará ornamental pepper seedlings on benches colored with different wavelengths.

Material and Methods

Guaraci Cumari do Pará ornamental pepper seedlings grew from May 24 to July 5, 2022, at the State University of Mato Grosso do Sul (UEMS) in the Cassilândia Unit (UUC), located in Cassilândia (19º07'21" S, 51º43'15" W), with an altitude of 516 m. According to the Köppen climate classification, the region has a tropical rainy climate (Aw-type) with rainy summers and dry winters.

The location was an agricultural greenhouse with 150-micron low-density polyethylene (LDPE) film, light diffuser, anti-drip, and a 50% shading aluminized thermo-reflective mobile screen. With dimensions of 18.0 x 8.0 m x 4.0 m (144 m2), a zenithal opening became sealed with a 50% white screen and a monofilament screen with 50% shading on the sides and front.

The treatments consisted of colored laminated materials on the cultivation bench and a bench without reflective material (control) inside the experimental environment, thus emitting various wavelengths (Figs. 1 and 2). A completely randomized design operated with five treatments, six replications, and two plants per plot. Each reflective material covered an area of 1.0 m x 1.2 m, made of Formica® (laminated material).

Several treatments constituted the research experiment, i.e., T1: reflective bright blue laminate, T2: reflective bright red laminate, T3: reflective bright white laminate, T4: reflective bright yellow laminate, and T5: control (without reflective material on the surface of the cultivation bench).

Reflectance spectra data of the colored laminated reflective materials (Formica®) became accessible from a UV-Vis-NIR spectrophotometer (Model Lambda 1050, Perkin Elmer), ranging from 1 nm to 100 nm min-1. Small discs of the laminates (1 cm) entered the sample holder of an integration sphere with a radius of 150 mm (Fig. 2)

The pots (1.0 dm3) contained Carolina Soil® substrate. Each pot received two seeds. After emergence, seedling thinning with scissors allowed for more root growth, thus leaving one plant per pot. The pots had an arrangement of rows that were 5 cm apart. The seedlings were watered twice daily, in the morning and afternoon

when necessary.
At 45 d after sowing, we evaluated seedling height (SH, cm), stem diameter (SD, mm), number of leaves (NL), shoot dry matter (SDM, g), and root dry matter (RDM, g). The height of the seedlings was measured using a graduated ruler, measuring the distance from the base to the apex of the stem meristem. The dry matter of the shoot and root was measurable after drying in an air-forced circulation oven at 65 °C for 72 h and weighed on an analytical balance. The total dry matter (TDM, g), the shoot dry matter/root dry matter ratio (SRR), the seedling height/stem diameter ratio (HDR), the root dry matter/total dry matter ratio (RTR, %), and Dickson's quality index (DQI) (Dickson et al., 1960) were measurable after determining plant total dry mass (numerator) divided by the summation of SQ and S: R ratio (denominator).

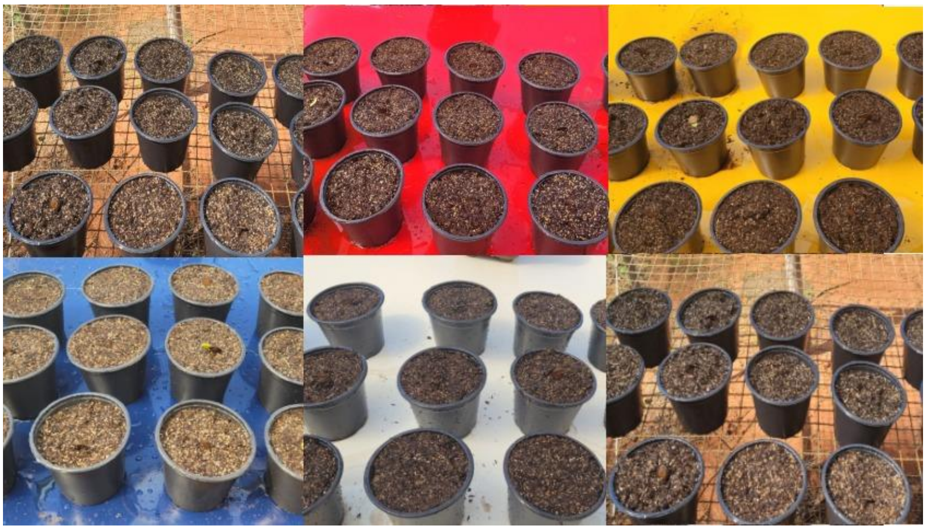

Fig. 1. Colored laminates and the pots on cultivation benches.

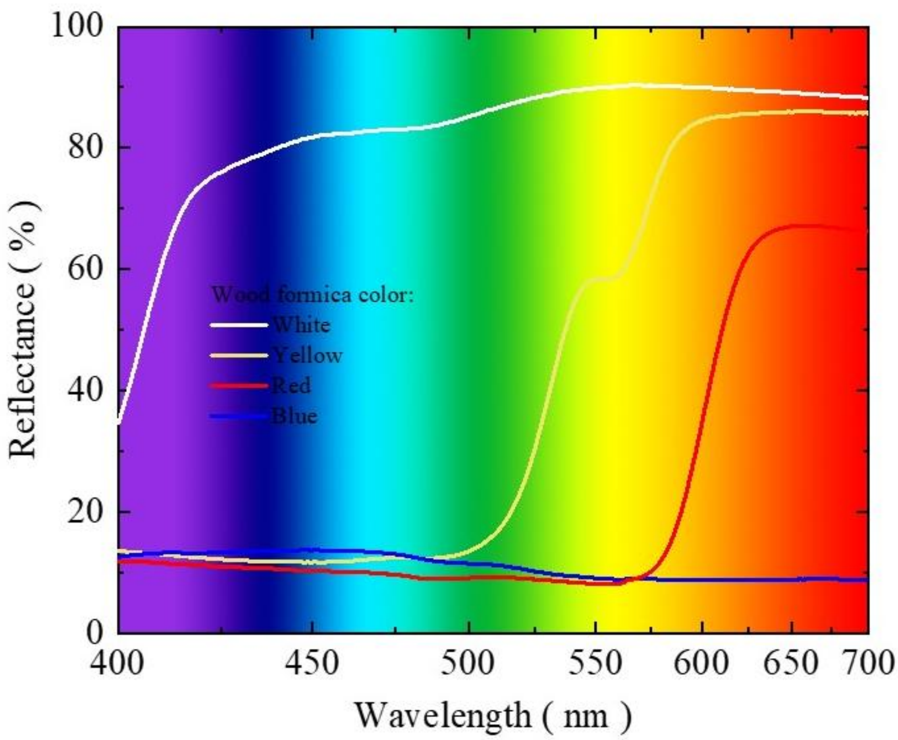

Fig. 2. Reflectance of the laminates used on the cultivation benches for growing Guaraci Cumari do Pará pepper seedlings. Source: Dr. Sandro Marcio Lima and Dr. Luis Humberto da Cunha Andrade (State University of Mato Grosso do Sul/Dourados).

Chlorophyll content, carotenoids, and pheophytin were measurable in leaf samples. Extractions of chlorophylls (a and b), carotenoids, and pheophytin (a and b) followed a method by Lichtenthaler (1987). Samples of fresh plant material (0.5 g) and 5 mL of 80% acetone were mixed and stored in 14 mL test tubes in a refrigerator for 48 h. After this period, the test tubes entered a centrifuge device for 15 min, operating at 4,000 rpm, followed by supernatant dilution in a ratio of 0.3 mL extract to 1.7 mL of 80% acetone. Measurements appeared on a spectrophotometer at specific wavelengths, i.e., 470, 647, 653, 663, and 665 nm.

Photosynthetically active radiation (PAR) (µmol m^{-2} s^{-1}) was monitored on the cultivation benches using a portable digital pyranometer (Apogee®) at 9:30 am. (Amazon time – AMT). We compared PAR data in a randomized block design with seven repetitions. Each repetition had six collection days. The statistical software Sisvar 5.3 (Ferreira, 2010) evaluated mean values submitted to the F test and compared them using the LSD test for growth parameters and pigment traits ($P \leq 0.05$). Using Tukey's test, the photosynthetic-active radiation data were assessable ($P \leq 0.05$).

Results

The photosynthetically active radiation (PAR) in the experimental environment was 647.40 µmol m^{-2} s^{-1}. In full sun, it was 1445.37 µmol m^{-2} s^{-1}, which showed a decrease by 55%. The lowest PAR reflectance was observed in the control, blue, and red laminates, and the highest on the white and yellow (Fig. 3A). Compared to the control, the blue, red, white, and yellow laminates reflected 21, 81, 397, and 218%, respectively (Fig. 3A). The cultivation bench with white laminate reflected 16.6% of the daily average PAR (647.40 µmol m^{-2} s^{-1}) recorded in the experimental environment (Fig. 3B) and promoted greater radiation availability for photosynthesis.

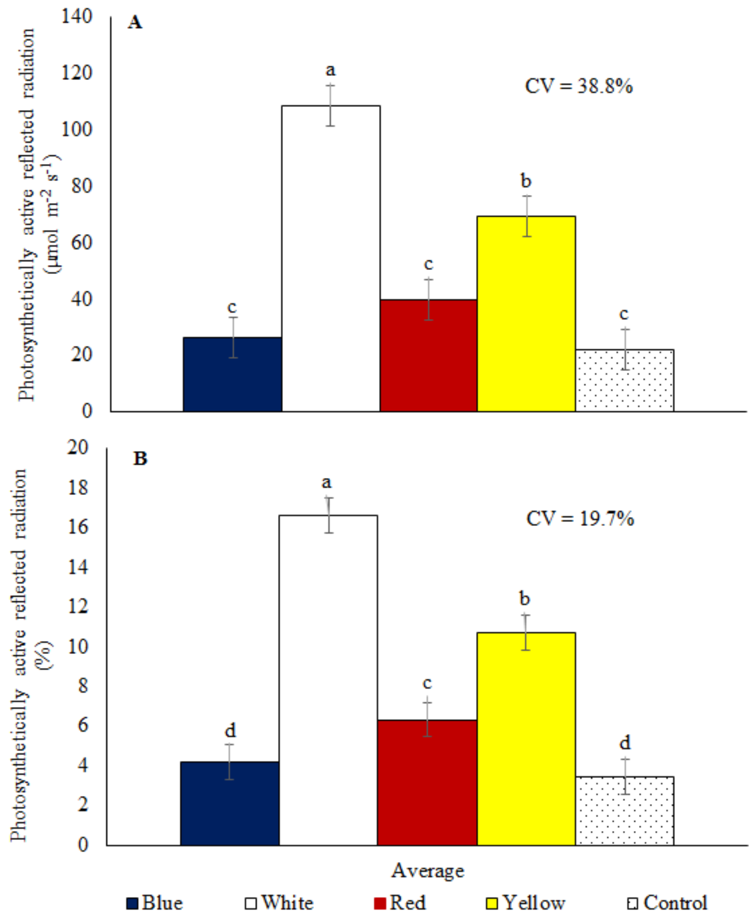

Fig. 3. Photosynthetically active radiation reflected (µmol m^{-2} s^{-1}) by the cultivation benches (A) and percentage reflected from the photosynthetically active radiation inside the experimental environment by the cultivation benches (B) in producing seedlings of Guaraci Cumari do Pará (*Capsicum chinense*) ornamental pepper. CV = coefficient of variation. Means followed by the same letter do not differ by Tukey's test ($P \leq 0.05$). Vertical bars indicate standard errors.

No significant differences were observed in seedling height, stem diameter, shoot dry matter/total dry matter ratio, and root dry matter/total dry matter ratio (Table 1). Significant differences occurred in the other variables (Table 1).

Table 1. Analysis of variance for seedling height (SH), stem diameter (SD), number of leaves (NL), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), shoot dry matter/root dry matter ratio (SRR), seedling height/stem diameter ratio (HDR), root dry matter/total dry matter ratio (RTR), Dickson's quality index (DQI), chlorophyll a (CLA), chlorophyll b (CLB), total chlorophyll (CLT), carotenoids (CRT), pheophytin a (PPA), pheophytin b (PPB), total pheophytin (PPT), chlorophyll a/b ratio (CAB), total chlorophyll/carotenoids ratio (CCR), and total chlorophyll/pheophytin ratio (CPR) of Guaraci Cumari do Pará ornamental pepper seedlings (*Capsicum chinense*) on various reflective color benches with various wavelengths. Cassilândia, 2022.

	SH	SD	NL	SDM	RDM	TDM	HDR	SRR	DQI	RTR
Benches	ns	ns	**	**	**	**	**	ns	**	ns
CV (%)	8.84	6.68	4,51	9.64	16.68	10.85	4.99	13.84	13.09	8.88
	CLA	CLB	CLT	CRT	PPA	PPB	PPT	CAB	CCT	CPR
Benches	**	**	**	**	**	**	**	**	**	**
CV (%)	4.92	5.07	4.88	4.50	4.43	11.52	4.93	2.45	1.35	0.30

ns = not significant, * and ** significant at 5% and 1% by the F-test. CV = coefficient of variation.

The number of leaves was highest in the control treatment (51.70) (Fig. 4A). The lowest number of leaves was observed on the white laminate (45.20), 13% less than in the control treatment, while on the blue and red laminates, the number of leaves was 6% less than in the control treatment. The blue laminate caused maximum seedling height, with a 15% increase compared to the control treatment. The lowest seedling height was observed on the white laminate and control treatment (Fig. 4B). The yellow laminate on the cultivation bench caused maximum stem diameter but was not significantly different from the blue, red, and white laminates and the control treatment (Fig. 4C).

The shoot dry matter was highest on the bench with the control treatment (0.53 g), followed by the blue laminate (0.51 g) (Fig. 4D). Regarding root and total dry matter, the highest value was observed in the control treatment (Fig. 4E, F). The lowest dry matter value occurred in plants on the white laminate, with a 34% decrease in the shoot dry matter, 29% in the root dry matter, and 33% in the total dry matter compared to the control treatment.

Dickson's quality index reached maximum value in seedlings of the control treatment (0.135). The lowest value occurred in the bench with white laminate (0.091), a 33% reduction compared to the control treatment (Fig. 5A). The highest seedling height/stem diameter ratio values were observed in cultivation benches with blue and red laminates, with an increase of 12 and 13%, respectively, compared to the control treatment (Fig. 5B). The root dry matter/total dry matter ratio was higher in the cultivation bench with white laminate (35.6), without significant differences between the treatments (Fig. 5C). The shoot dry/root dry matter ratio (SRR) was higher in plants on the cultivation bench with blue laminate (2.1), although without significant differences between the treatments (Fig. 5D).

The highest chlorophyll a, b, and total chlorophyll contents appeared in cultivation benches with blue, red, and yellow laminates (Fig. 6A, B, C). Chlorophyll a content increased by 41, 49, and 44% with the blue, red, and yellow laminates on the cultivation benches compared to the control treatment, respectively (Fig. 6A). Chlorophyll b increased by 36, 34, and 31% with the blue, red, and yellow laminates on the bench, respectively (Fig. 6B). Total chlorophyll increased by 39, 45, and 40% with the blue, red, and yellow laminates on the cultivation benches, respectively (Fig. 6C). The white laminate on the cultivation bench caused a decrease in chlorophyll a, b, and total chlorophyll by 7, 19, and 10%, respectively.

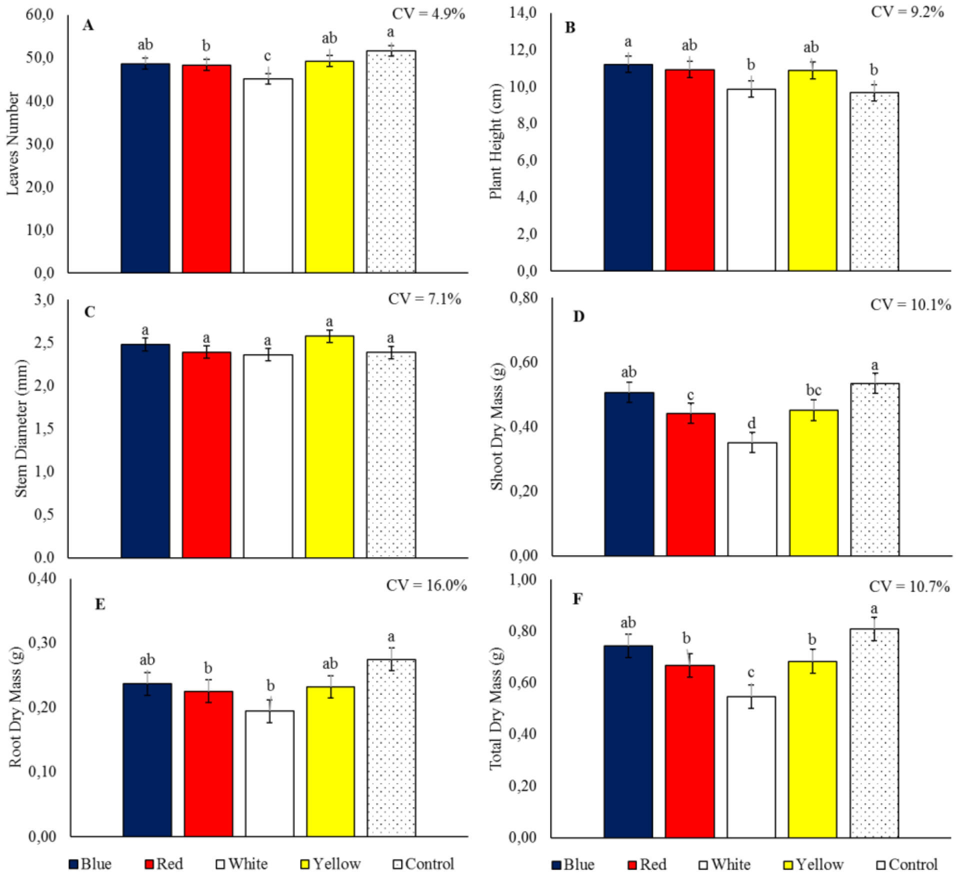

Fig. 4. Number of leaves (A), seedling height (B), stem diameter (C), shoot dry matter (D), root dry matter (E), and total dry matter (F) of seedling of Guaraci Cumari do Pará (*Capsicum chinense*) ornamental pepper produced with different reflective colored materials (representing different wavelengths) on the cultivation benches. Mean values followed by the same letter for each variable do not differ by the LSD test. Vertical bars indicate standard errors.

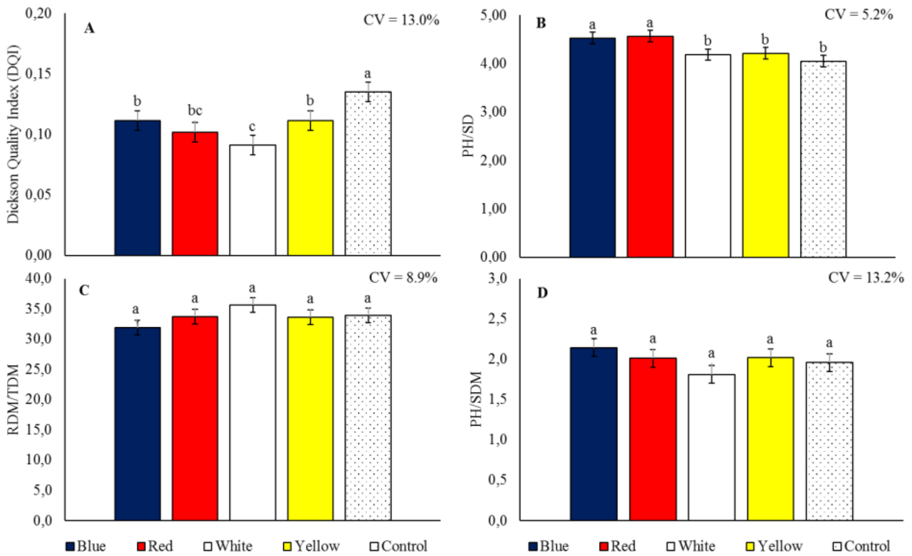

Fig. 5. Dickson's quality index (A), seedling height/stem diameter ratio (SH/SD = HDR) (B), root dry matter/total dry matter ratio (RDM/TDM = RTR) (C), and shoot dry matter/root dry matter ratio (SDM/RDM = SRR, %) (D) of seedling of Guaraci Cumari do Pará (*Capsicum chinense*) ornamental pepper produced with different reflective colored materials (representing different wavelengths) on the cultivation benches. Means followed by the same letter for each variable do not differ by the LSD test. Vertical bars indicate standard errors.

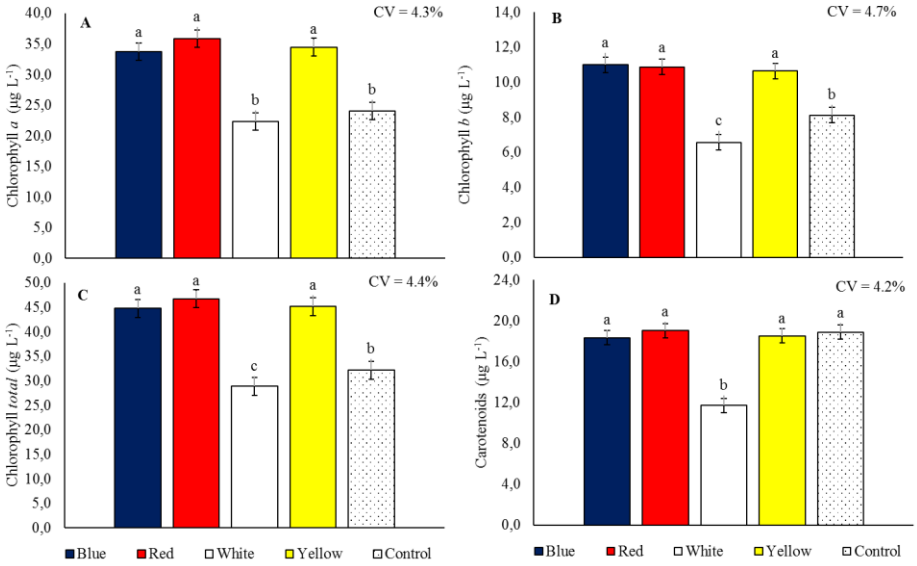

Fig. 6. Chlorophyll a (A), chlorophyll b (B), total chlorophyll (C), and carotenoids (D) of seedlings of Guaraci Cumari do Pará (*Capsicum chinense*) ornamental pepper produced with different reflective colored materials (representing different wavelengths) on the cultivation benches. Mean values followed by the same letter for each variable do not differ by the LSD test. Vertical bars indicate standard errors.

The carotenoid content did not differ significantly in plants of the control treatment (18.87 µg L^{-1}) and blue (18.34 µg L^{-1}), red (19.02 µg L^{-1}), and yellow (18.50 µg L^{-1}) laminates. However, in the cultivation bench with white laminate, there was a 38% reduction compared to the control treatment (Fig. 6D).

The total chlorophyll/carotenoids ratio had the lowest value in the control treatment (1.70). The blue, red, white, and yellow laminates caused an increase of 43, 44, 45, and 43% in the total chlorophyll/carotenoids ratio, respectively (Fig. 7A). The chlorophyll a/b ratio was highest in plants on the bench with white laminate, with a 15% increase compared to the control treatment, followed by the second highest value on the cultivation bench with red laminate, with a 12% increase (Fig. 7B). The yellow laminate on the cultivation bench caused a 10% increase compared to the control treatment. The lowest values occurred in the control treatment (3.0) and the cultivation bench with blue laminate (3.1).

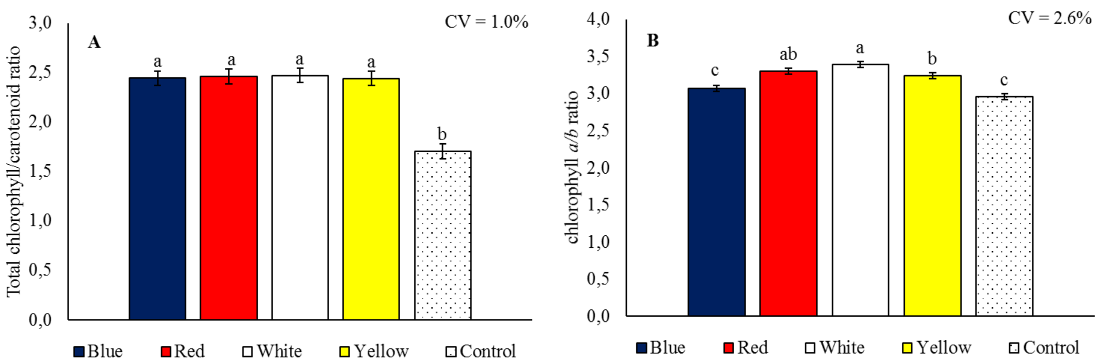

Fig. 7. Total chlorophyll/carotenoid ratio (A) and chlorophyll a/b ratio (B) of Guaraci Cumari do Pará (*Capsicum chinense*) ornamental pepper seedlings produced with different reflective colored materials (representing different wavelengths) on the cultivation benches. CV = coefficient of variation. Mean values followed by the same letter do not differ significantly by the LSD test. Vertical bars indicate standard errors.

Discussion

The cultivation benches with different colors reflect sunlight wavelengths to the cultivated plants and cause changes in PAR, resulting in changes in the morphological characteristics, photosynthetic pigments, and quality of the pepper seedlings. The colors of the cultivation benches provided diffused light absorption of some spectra, affecting the quality of the light (Amaro de Sales et al., 2021). The color type had different intensities and qualities of sunlight (Holcman and Sentelhas, 2013; Amaro de Sales et al., 2021), which can alter the characteristics of the plants (Holcman and Sentelhas, 2013; Ilic et al., 2022; Abidian et al., 2023; Davarzani et al., 2023).

In *Piper hispidinervum*, 50% shading with red and blue cover provided greater plant height, stem diameter, and number of leaves (Lima et al., 2017). *Ocimum selloi* also showed increased growth when grown in an environment with blue and red reflectance (Costa et al., 2010). Roses cultivated with supplemental light improved the vegetative growth, biomass, and positive effects on flowering (Davarzani et al., 2023). Light supplementation significantly affected sweet pepper, thus increasing the dry weight, stem height, and stem diameter (Abidian et al., 2023).

Shading with red mulch increased plant height, diameter, and number of leaves in bromeliads (*Aechmea fasciata*). The authors stated the inadaptability of the crop to conditions of excess light and its impaired development in these conditions, while red light assisted with crop growth (Holcman and Sentelhas, 2013).

The use of red or blue light reflectors can be interesting because chlorophylls mainly absorb red and blue wavelengths from the visible spectrum for the photosynthetic process (Taiz et al., 2017). Campos et al. (2023) observed more leaves and fruits in tomato plants grown on benches with red laminate.

Experimental environments protect the plant from biotic and abiotic stresses, such as excess light and insect incidence, thus manipulating the reflected spectrum using different colors that alter the physiological response and can improve light absorption (Ilic et al., 2022). The white laminate on the cultivation bench caused a reduction in the number of leaves, stem diameter, dry matter of the shoot, roots, and total, and Dickson's quality index (DQI) due to the reduction in chlorophyll and carotenoid levels observed in this treatment. Excess light can cause degradation and a consequent decrease in chlorophyll levels (Lima et al., 2017). Lowered chlorophyll levels hamper photosynthesis and retard seedling growth.

Moosavi-Nezhad et al. (2021) did not observe differences in DQI in grafted watermelon seedlings using different light intensities. However, leaf area, specific leaf area, leaf mass ratio, and root length changed in response to light quality. Chrysanthemums showed maximum aerial biomass in response to blue light, where the leaf area and length varied in response to red, blue, and far-red light wavelengths (Moosavi-Nezhad et al., 2022).

This study demonstrated that photosynthetic pigment levels increased in response to blue, red, and yellow laminates on the cultivation benches, resulting in taller plants. The blue laminate on the cultivation bench provided a high accumulation of shoot, root, and total dry matter, significantly equaling the control treatment.

Conclusions

The color of laminates on the benches provided different levels of reflected photosynthetically active radiation, influencing several characteristics in the pepper seedlings. Seedlings on the control bench performed better in growth rate and Dickson's quality index. The blue, red, and yellow laminates on cultivation benches caused higher levels of chlorophylls and pheophytins. The white laminate on the cultivation bench was unsuitable for pepper seedling production, as it adversely affected morphological characteristics, photosynthetic pigments, and seedling quality.

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Conflict of Interest

The authors indicate no conflict of interest in this work.

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