Domingues MM *et al.* (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 2, Article number 14498
DOI:10.15835/nbha53214498
Research Article

Colored benches improved quality of ornamental pepper

Myrella de M. DOMINGUES, Giovana P.V. da SILVA, Rita de C.B. NUNES, Paulo H.R. MELO, Edilson COSTA*, Fernanda P. de A.P. BORTOLHEIRO, Flávio F. da S. BINOTTI, Eduardo P. VENDRUSCOLO, Gustavo H. da C. VIEIRA

*University of State of Mato Grosso do Sul, Department of Agronomy, MS 306 Highway, Cassilândia/MS, Zip Code: 79540-000, Brazil; myrelladomingues2604@gmail.com; giovanapnhr@gmail.com; ritab205@gmail.com; paulorosa.geo@gmail.com; edilson.costa@uems.br (*corresponding author); fernanda.bortolheiro@uems.br; binotti@uems.br; eduardo.vendruscolo@uems.br; gcv@uems.br*

Abstract

Ornamental pepper species belonging to the *Solanaceae* family and the *Capsicum genus* have gained commercial visibility and high demand due to their morphological diversity. Growing ornamental plants in protected environments offers considerable advantages, allowing for more precise management of micrometeorological elements. This study aimed to evaluate the influence of colored benches in the biometric aspects, photosynthetic pigments, and gas exchange of the ornamental pyramid pepper. The experiment was conducted in a greenhouse, covered with low-density polyethylene film and aluminized mesh with 42-50% shading under the film and side screens with 30% shading. The wavelengths were promoted by reflective colored laminates on the growing benches. Five treatments were assessed in a completely randomized design with four replications and five plants per plot, as follows: bright white laminate material, bright yellow laminate material, bright red laminate material, bright dark blue laminate material, and control – with no material on the surface of the growing bench. The colors (white, yellow, and red) increased the supply of photosynthetically active radiation except for blue. The colors increased pepper fruit production, with the white, yellow, red, and blue colors promoting increases of 37.5%, 27.6%, 26.5%, and 42.2%, respectively. The colors influenced and promoted ornamental pepper plants with higher biometric quality than the control, showing the influence of the wavelength in promoting plant quality, both visually and in terms of fruit quantity, essential aspects in the marketing of ornamental plants.

Keywords: *Capsicum frutescens;* gas exchange; ornamental pepper 'Pyramid'; photosynthetically active radiation

---

Introduction

The fruits of the *Capsicum genus*, known as chili peppers, are correlated with properties that favor health, which can be attributed to their nutritional composition and the presence of specific metabolites, among these properties are analgesic, anti-obesity, cardioprotective, pharmacological, neurological, and dietary

Received: 23 Mar 2025. Received in revised form: 06 Jun 2025. Accepted: 27 Jun 2025. Published online: 30 Jun 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

effects, among others (Mendes and Gonçalves, 2020). The specific phytochemicals linked to these properties include carotenoids (precursors of vitamin A), phenolic compounds, and capsaicinoids (Xiao *et al.*, 2019; Cisternas-Jamet *et al.*, 2020; Nornberg *et al.,* 2021).

Research related to the pepper plants (*Capsicum* spp.) is aimed at economic gains, overcoming the morphological challenges of growing conditions and expanding its uses for food, medicinal, condiment, and ornamental purposes by adding value to its forms of consumption and/or use. Ornamental pepper species belonging to the *Solanaceae* family and the *Capsicum genus* have gained commercial visibility and high demand due to their morphological diversity, fruit variation in terms of shape, size, and color, as well as the diversity of types and levels of pungency (Santos *et al.*, 2023).

Growing ornamental plants in protected environments offers significant advantages, enabling precise management of micrometeorological factors such as temperature, humidity, and radiation (Lefsrud *et al.*, 2006; Campos *et al.*, 2023). Light plays a fundamental role in plant growth, influencing physiological processes like photosynthesis, which converts light energy into chemical compounds essential for growth and development (Taiz *et al.*, 2015; Kang *et al.*, 2023). The type of protected environment with its different size configurations, different covering materials, their interactions with reflective silver material on the growing bench, pot colors, and bench colors, alter the proportion of photosynthetically active radiation (PAR) available to the plants, not only in quantity but also in quality, favoring plant performance (Araújo *et al.*, 2024; Bortolheiro *et al.*, 2025). The PAR, the visible range of the solar spectrum, is essential for the photosynthetic process and plant development (Villalobos and Fereres, 2016; Taiz *et al.*, 2015), as interactions between plants and light occur through specific pigments found in chloroplasts, which capture light energy, and photoreceptors, which are proteins capable of triggering different responses based on light conditions (Holopainen *et al.*, 2018).

The predominant plant photoreceptors in pepper plants have specific peak absorbance wavelengths, such as phytochromes (600-800 nm), phototropins (390-500 nm), cryptochromes (320-500 nm), and UV-B 8 resistance photoreceptors (UVR8) (280-315 nm), light perception through photoreceptors play a central role in modulating the biosynthesis of phytochemicals such as carotenoids, phenolic compounds, and capsaicinoids, directly affecting the chemical composition and health benefits of plants (Jiménez-Viveros *et al.*, 2023).

Diversifying and altering the internal light conditions of protected environments can promote possibilities for plants to increase their yield potential, and for this, there are sophisticated systems (air conditioning and indoor) and unsophisticated ones (greenhouses and screens no climatization). Light supplementation by LEDs is a much studied alternative (Adibian *et al.*, 2023; Davarzani *et al.*, 2023), however, studies show the possibility of using colored reflective material on vegetable growing benches promoting growth (Cavalcante *et al.*, 2021; Campos *et al.,* 2023).

Given the above, this study aimed to evaluate the influence of colored benches in the biometric aspects, photosynthetic pigments, and gas exchange of the ornamental pepper 'Pyramid'.

Materials and Methods

The experiment with the ornamental pepper 'Pyramid' (*Capsicum frutescens*) was conducted at the Mato Grosso do Sul State University (UEMS), Cassilândia Campus, in Cassilândia, MS, Brazil, from October 20, 2023 to January 22, 2024. The location has a latitude of -19.1225° (19°07'21"S), a longitude of -51.7208° (51°43'15" W), and an altitude of 516 m (Cassilandia A742 automatic station).

The experiment was conducted in a greenhouse measuring 18.0 m long x 8.0 m wide x 4.0 m high under the gutter (144 m^2 area), covered with 150-micron low-density polyethylene (LDPE) film, light diffusing, with a zenith opening sealed with 50% white mesh, with side and front monofilament mesh with 30% shading. Underneath the LDPE film was a movable aluminized heat reflecting screen with 42-50% shading.

Inside the protected environment, bright-colored laminate reflective materials (Fórmicas®), they are called laminated muches, were tested on the growing benches in a completely randomized design, with five treatments and four replications, with ten plants per repetition, totalling forty plants per treatment. The treatments were called: control, no material on the bench surface; bench covered with bright white laminate; bench covered with bright dark red laminate; bench covered with bright dark blue laminate, and bench covered with bright yellow laminate.

The metal growing benches were 1.40 m wide x 3.50 m long x 0.80 m high, and each reflective material covered an area of 1.03 m x 1.25 m (1.20 m^2), 1.0 m apart (Figure 1), where each replica was 100 cm away from each other, so that there was no interference from one treatment to the other. The colored 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. The reflectance of the laminates in a dominant wavelength: the white laminates range from 425 to 700 nm, the yellow laminate range from 525 to 700 nm, the red laminate range from 625 to 700 nm and the blue laminate is iqual from 400 to 700 nm, as described by Bortolheiro *et al.* (2025).

To produce the 'Pyramid' ornamental pepper (*Capsicum frutescens*), 1.0 L black pots containing Carolina Soil® substrate were used (Carolina Soil, Carolina Soil Company, Santa Cruz do Sul, Rio Grande do Sul, Brazil), the substrate was composed of sphagnum peat, expanded vermiculite, dolomitic limestone, agricultural gypsum and NPK fertilizer (trace amounts). 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. The sowing took place on October 20, 2023. Slow-release fertilizer, composed of 15% nitrogen, 9% phosphorous, 12% potassium, 1.3% magnesium, 6% sulphur, 0.05% copper, 0.46% iron and 0.02% molibdenium (FORTH® Garden; with NPK + 9 nutrients, São Paulo, São Paulo, Brazil) was used at the recommended dose of 12g per pot at sowing, and at 42 days after sowing (DAS), a post-planting dose of 4g was used. The seedlings were irrigated twice daily, morning and afternoon, using micro-sprinklers when necessary (micro-sprinkler system with NETAFIM SPINNET emitters with an irrigation capacity of 70 liters per hour).

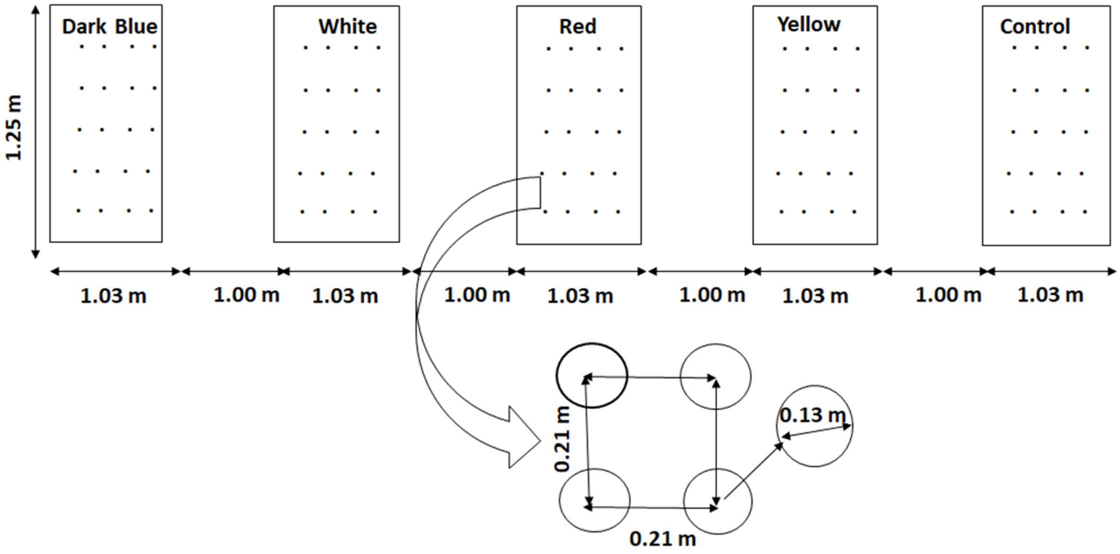

Figure 1. Bright colored benches and control

At 58 days after sowing (DAS), the following parameters were assessed: plant height (PH1), number of flower buds (NFB1), and number of leaves (NL). At 88 DAS, additional measurements included plant height (PH2), number of flower buds (NFB2), number of flowers (NF), and number of fruits (NFR). Physiological assessments conducted at 88 DAS included internal CO_2 concentration (Ci), transpiration rate (E), stomatal conductance (gs), CO_2 assimilation rate or net photosynthesis (A), water use efficiency ($WUE = A/E$), and instantaneous carboxylation efficiency ($EiCi = A/Ci$).

Plant height (PH) was measured using a ruler, measuring the distance from the base to the apex of the stem and the number of flower buds and fruits obtained by counting. To determine internal CO_2 concentration (*Ci*), transpiration rate (*E*), stomatal conductance (*gs*), CO_2 assimilation rate (*A*), or net photosynthesis, a portable infrared gas exchange meter (Lci, ADC Bioscientific, Hertfordshire, UK) was used at 9 a.m., measurements were taken on the upper third of the plants, in fully expanded and physiologically mature leaves. Subsequently, the water use efficiency (WUE=A/E) (ratio between net photosynthesis and transpiration rate) and the instantaneous carboxylation efficiency (*EiCi=A/Ci*) (ratio between net photosynthesis and internal intracellular CO_2 concentration) were calculated.

The contents of chlorophyll a (CLA), chlorophyll b (CLB), total chlorophyll (CLT), and carotenoids (CRT) were determined at 88 DAS, and the chlorophyll a/b ratio was estimated. Chlorophylls (a and b) and carotenoids were extracted following the methodology of Lichtenthaler (1987). A sample of 0.5 g of fresh plant material was weighed, 5 mL of 80% acetone was added, and the material was stored in 14 mL test tubes for 48 hours in a refrigerator at 25 °C. After this period, the test tubes were centrifuged for 15 minutes at 4,000 rpm, and then the supernatant extract was diluted in a ratio of 0.1 mL of extract to 1.9 mL of 80% acetone. Measurements were made on a spectrophotometer (model Kasuaki, brand IL-226-NM, Tokyo, Japan) at wavelengths of 470 nm, 647 nm, 653 nm, 663 nm, and 665 nm.

The reflected photosynthetically active radiation (PAR) (µmol $m^{-2}s^{-1}$) of the growing benches was monitored using a portable digital pyranometer (Apogee® Apogee Instruments, Inc., United States of America) every day at 9:30 a.m. on days when the sky was clear or slightly cloudy. The percentage of radiation reflected by the benches was determined according to the internal radiation of the protected environment, where the incident radiation was considered 100%, and the reflected radiation was obtained by a rule of three. The PAR data was compared in a randomized block design with four replications. The average external and internal photosynthetic radiation was 1993.9 and 495.9 µmol $m^{-2}s^{-1}$, respectively. The external radiation (full sun) and the internal radiation in the environment were collected with the sensor facing upwards and the reflected radiation by the benches the sensor was facing downwards.

The data were subjected to analysis of variance and the means were compared by the LSD test at 5% probability. A multivariate analysis was conducted using principal components (PCA), using the R software version (v. 4.1.0), with the Ggfortify and Factoextra packages (R Core Team, 2023). The data was also subjected to Pearson's correlation analysis (R software version v. 4.3.3 Corrplot package), using the correlation matrix with different color gradients between the study variables. The relationships were determined as follows: the closer to the blue color, positive correlations were highlighted, while negative correlations were highlighted in red. Correlations with 0.05% error were marked with one asterisk, correlations with 0.01% error with two asterisks, and correlations with 0.001% error with three asterisks.

Results

The average external and internal photosynthetic radiation was 2014.8 and 624.8 µmol m^{-2} s^{-1}, respectively. The white and yellow laminates reflected the most photosynthetically active radiation (PAR) (Figure 2A and 2B). In percentage terms, all the laminates reflected more PAR than the control bench, as the white, yellow, red, and blue laminates amplified 487%, 295%, 110%, and 16%, respectively (Figure 2A). On average, the PAR of the white and yellow benches reflected 22.5% and 15% of the incident PAR inside the room (Figure 2B).

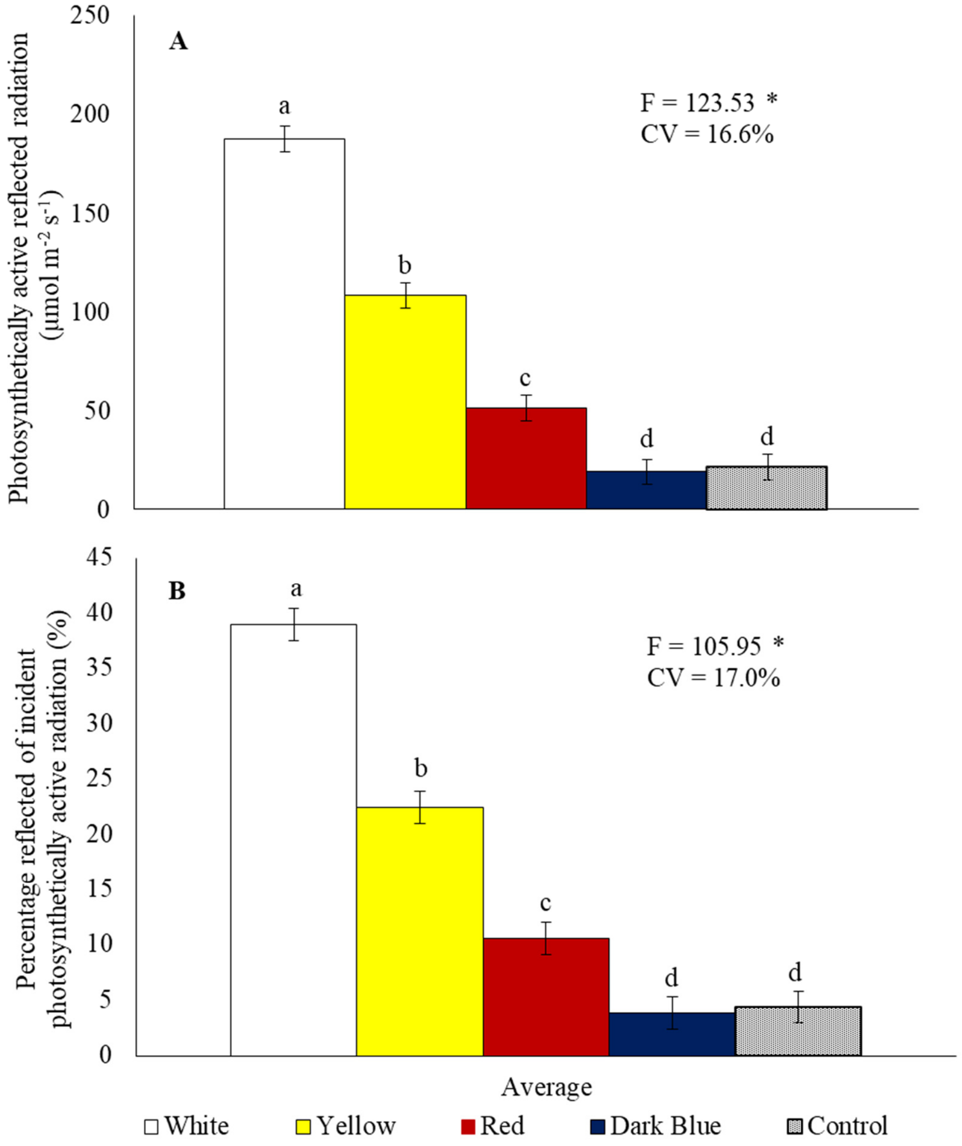

Figure 2. Photosynthetically active radiation reflected (μmol m^{-2} s^{-1}) (PAR) by the growing benches (A) and percentage of internal photosynthetically active radiation reflected by the colored growing benches (B) in the growing of 'Pyramid' ornamental pepper (*Capsicum frutescens*)

CV = coefficient of variation. Means followed by the same letter do not differ by the LSD test. Vertical bars correspond to the standard error

The plants grown on colored growing benches showed an increase in growth, producing taller plants than those grown on the control growing bench. At 58 DAS, the white, yellow, red, and blue colors promoted increases of 35.1%, 33.1%, 37.8%, and 34.2%, respectively, and at 88 DAS, these increases were 24.2%, 19.7%, 29.3% and 24.8% (Figure 3A).

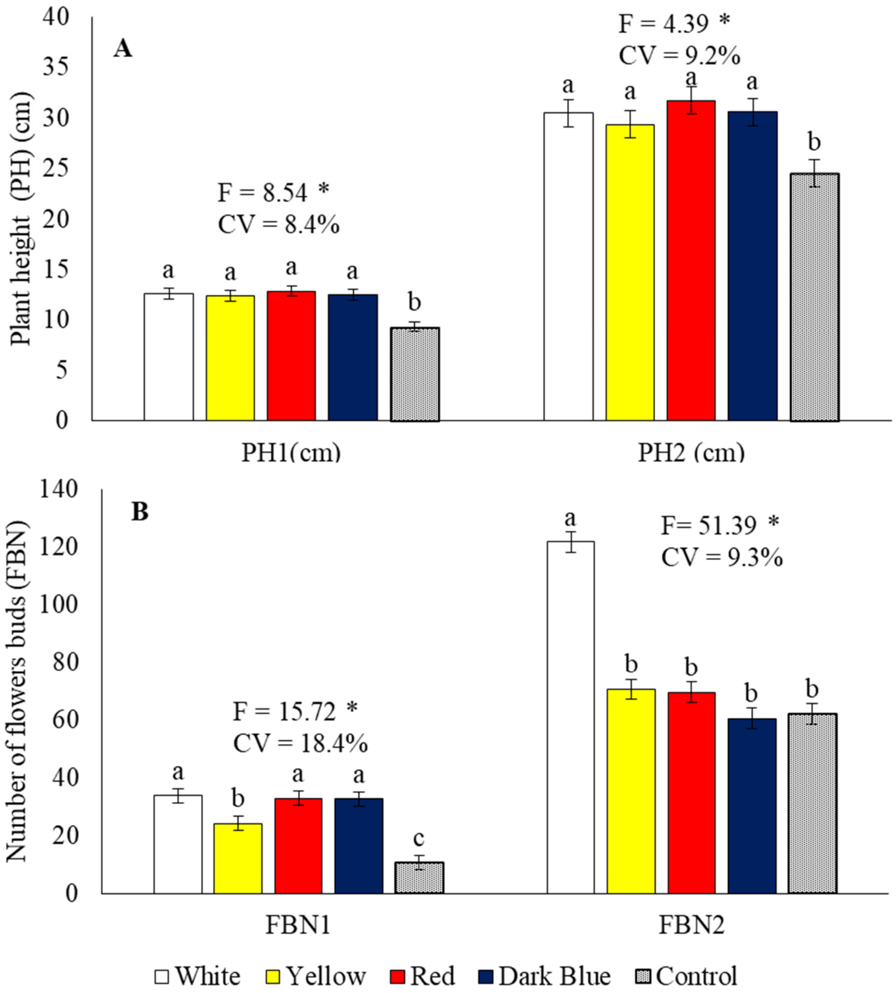

Figure 3. Plant height at 58 DAS (PH1) and 88 DAS (PH2) (A) and the number of flower buds at 58 DAS (FBN1) and 88 DAS (FBN2) (B) of the 'Pyramid' ornamental pepper (*Capsicum frutescens*) on different colored growing benches

CV = coefficient of variation. Means followed by the same letter for each variable do not differ by the LSD test. Vertical bars correspond to the standard error

At 58 DAS, the plants grown on the colored growing benches showed an increase in the number of flower buds compared to the control, and at 88 DAS, only the white color led to this increase. At 58 DAS, the number of flower buds on the white, yellow, red, and blue growing benches was 215%, 126%, 206%, and 204%, respectively, higher than on the plants grown on the control bench. At 88, the number of flower buds in the plants on the white growing bench was 96.7% higher than on the plants grown on the control bench (Figure 3B).

At 58 DAS, the white, red, and blue growing benches increased the number of leaves compared to the control, with the red color showing the greatest increase. At 58 DAS, the number of leaves on the white, red, and blue growing benches was 59.2%, 79.2%, and 55.2%, respectively, higher than those grown on the control bench (Figure 4A). Only the white color for the number of flowers led to an increase compared to the control at 88 DAS, increasing by 21.4% (Figure 4B). All the colors increased the number of fruits, which the white, yellow, red, and blue colors promoted increases of 37.5%, 27.6%, 26.5%, and 42.2%, respectively (Figure 4C).

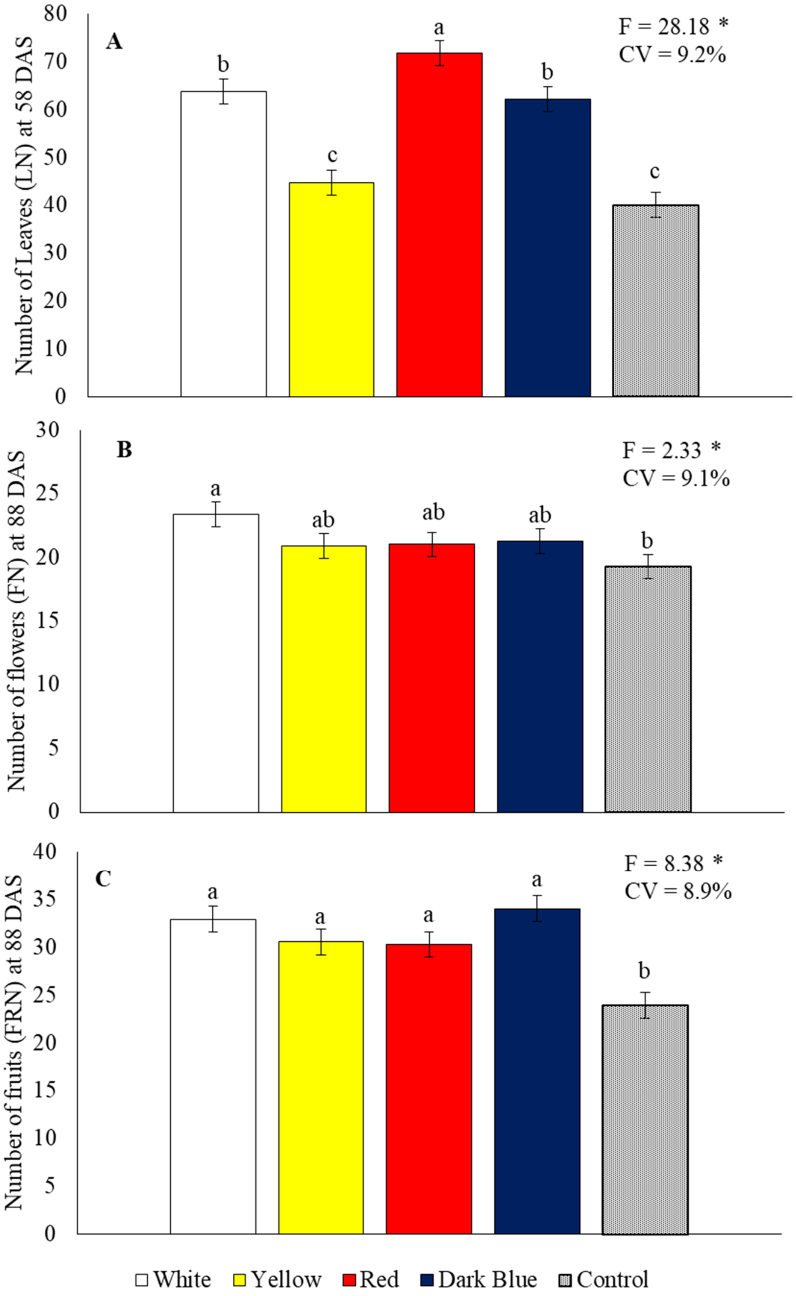

Figure 4. Number of leaves (NL) at 58 DAS (A), number of flowers at 88 DAS (FN) (B) and number of fruits at 88 DAS (NFR) (C) of the 'Pyramid' ornamental pepper (*Capsicum frutescens*) on different colored growing benches

CV = coefficient of variation. Means followed by the same letter for each variable do not differ by the LSD test. Vertical bars correspond to the standard error

The colors did not increase the chlorophyll and carotenoid contents compared to the control; however, among the colors, the yellow growing bench increased all these contents (Figures 5A, 5B, 5D, and 5E). The highest chlorophyll a/b and total chlorophyll/carotenoid ratios were observed on the control growing bench, followed by the dark blue growing bench (Figures 5C and 5F).

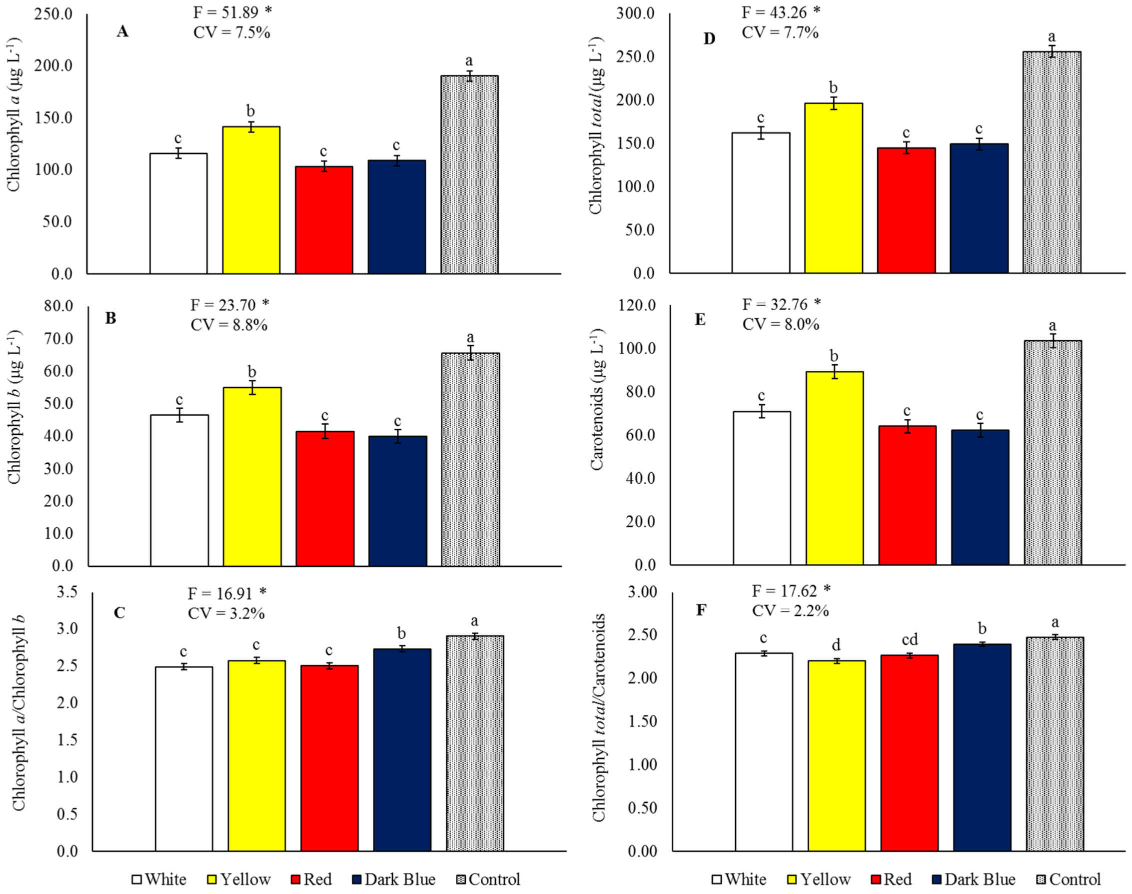

Figure 5. Chlorophyll a (A), chlorophyll b (B), chlorophyll a/b ratio (C), total chlorophyll (D), carotenoids (E), total chlorophyll/carotenoid ratio (F) of 'Pyramid' ornamental pepper (*Capsicum frutescens*) on different colored growing benches

CV = coefficient of variation. Means followed by the same letter for each variable do not differ by the LSD test. Vertical bars correspond to the standard error

The internal CO_2 concentration of the plants grown on the control growing bench was higher than those grown on the red growing bench (Figure 6A). The control growing bench had the highest plant transpiration rate (Figure 6B). The stomatal conductance of the plants on the red and control benches was higher than those grown on the white bench (Figure 6C). The CO_2 assimilation rate of the plants on the control growing bench was higher than those grown on the white and blue growing benches (Figure 6D). The treatments did not influence the water use efficiency of ornamental pepper plants, although dark blue and control growing bench have higher values, respectively 4.01 and 4.03 µmol CO_2 (Figure 6E). The instantaneous carboxylation efficiency of the plants on the red and control growing benches was higher than those on the dark blue growing bench (Figure 6F).

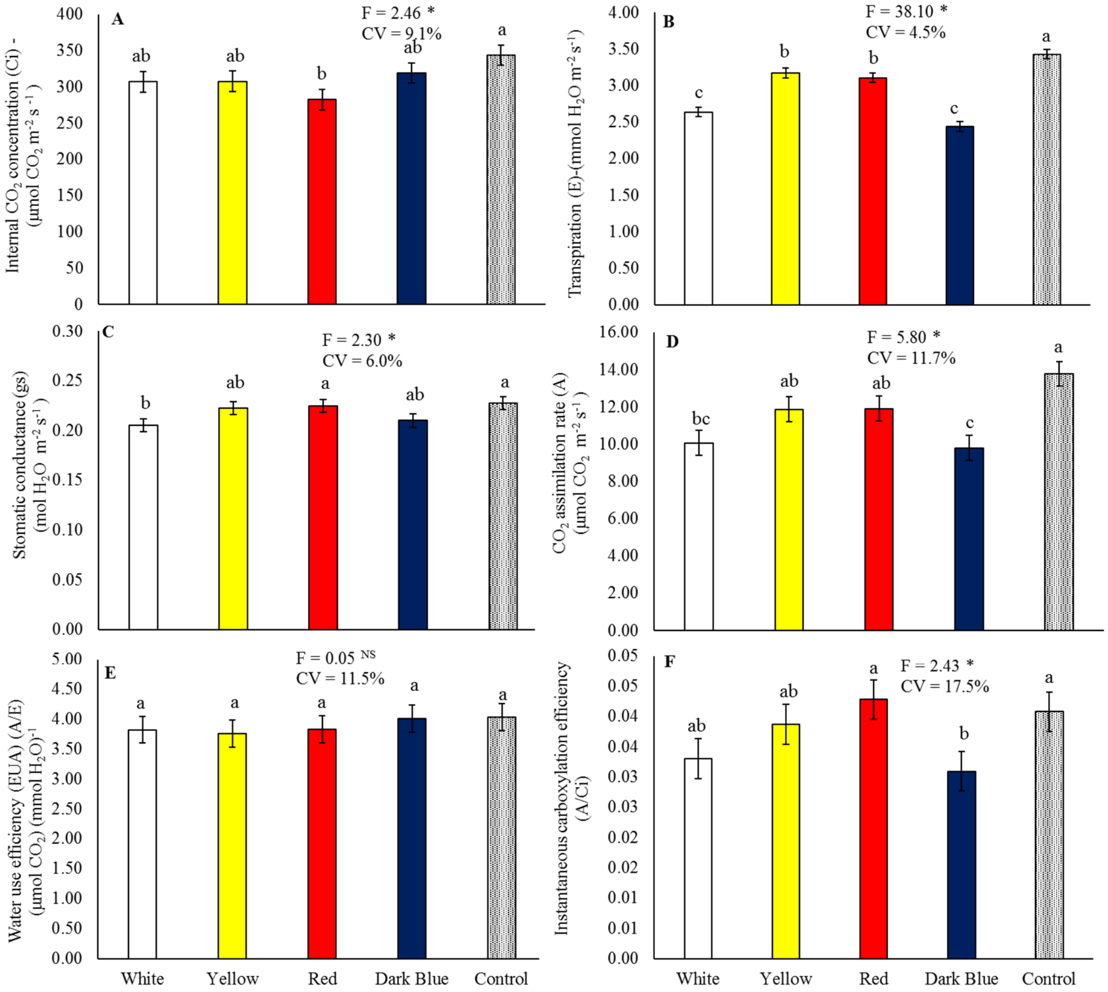

Figure 6. Internal CO_2 concentration (*Ci*) (A), transpiration rate (*E*) (B), stomatal conductance (*gS*) (C), CO_2 assimilation rate (*A*) (D), water use efficiency (*EUA*) (E), and instantaneous carboxylation efficiency (*A/Ci*) (F) of 'Pyramid' ornamental pepper (*Capsicum frutescens*) on different colored benches. CV = coefficient of variation. Means followed by the same letter for each variable do not differ by the LSD test. Vertical bars correspond to the standard error

Pearson correlation, which assesses the level of the interrelationship between the variables (Figure 7), showed that the growth variables (plant height, number of leaves, and number of flower buds) have a negative correlation with the photosynthetic pigment variables (chlorophyll and carotenoids), i.e., when pepper plants invest in the production of flower buds and number of leaves, they decrease the production of pigments in the leaves. The height of the plant and the number of leaves have a positive correlation with the number of flower buds, showing that the data is directly related, i.e., an increase in the value of one of them leads directly to an increase in the other, showing that taller plants with a greater number of leaves produce a greater number of flower buds. There was also a positive correlation in gas exchange, where an increase in the rate of CO_2 assimilation leads to an increase in transpiration rate (E) and stomatal conductance (*gs*).

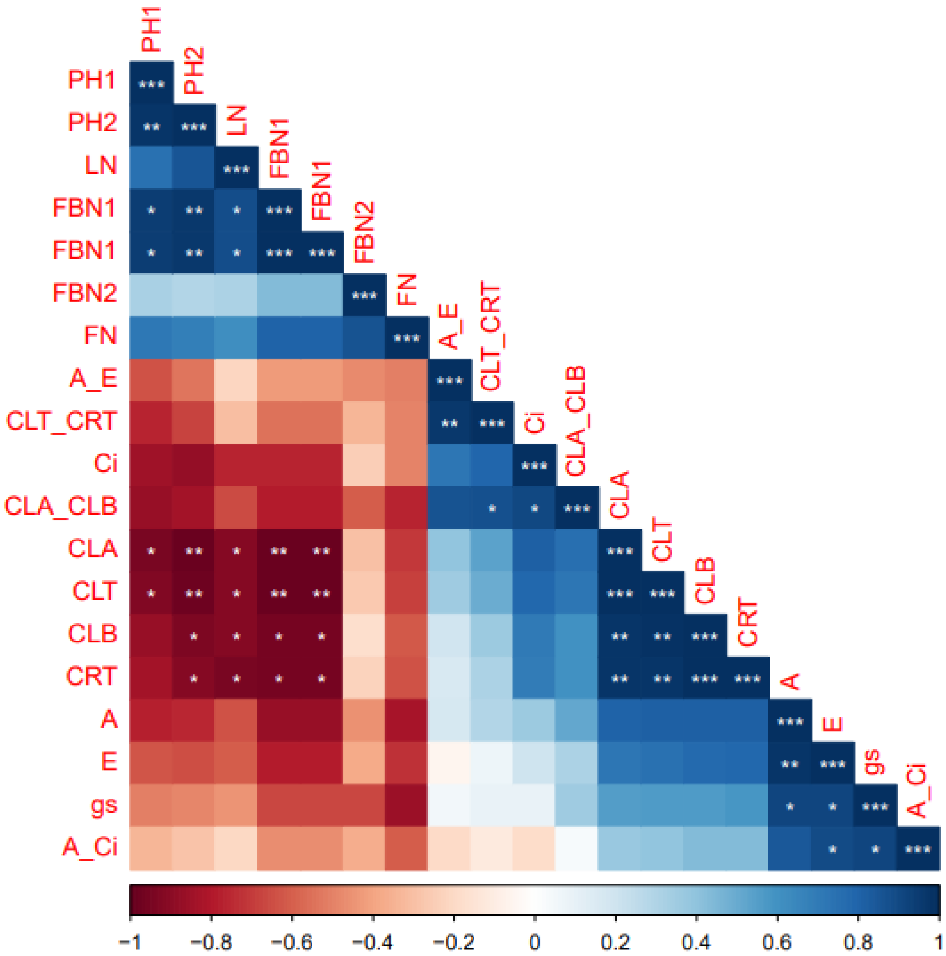

Figure 7. Pearson correlation for the variables plant height at 58 DAS (PH1) and 88 DAS (PH2) (A), number of flower buds at 58 DAS (NFB1) and 88 DAS (NFB2), number of leaves (NL) at 58 DAS, number of flowers (NF) at 88 DAS, number of fruits at 88 DAS (NFR), chlorophyll a (CLA), chlorophyll b (CLB), chlorophyll a/b ratio (CLA CLB), total chlorophyll (CLT), carotenoids (CRT), total chlorophyll/carotenoids ratio (CLT_CRT), internal CO_2 concentration (*Ci*), transpiration rate (*E*), stomatal conductance (*gs*), CO_2 assimilation rate (*A*), water use efficiency (*A_E*) and instantaneous carboxylation efficiency (*A_ Ci*) of the ‘pyramid’zornamental pepper (*Capsicum frutescens*) on different colored growing benches

In the principal component analysis results, the first component explained 84.5% of the variability in the data, while the second component explained 11.3% (Figure 8). It showed two groups of similarities (cluster), one formed by the different colored growing benches and the other with the control. The highest levels of photosynthetic pigments were found in the control, followed by the yellow-colored growing bench. The increase in the number of leaves caused a decrease in the photosynthetic pigments (Figure 8), similar to the Pearson correlation (Figure 7). The white-colored growing bench showed a strong relationship with the number of flower buds at 88 DAS (NFB2) (Figure 8).

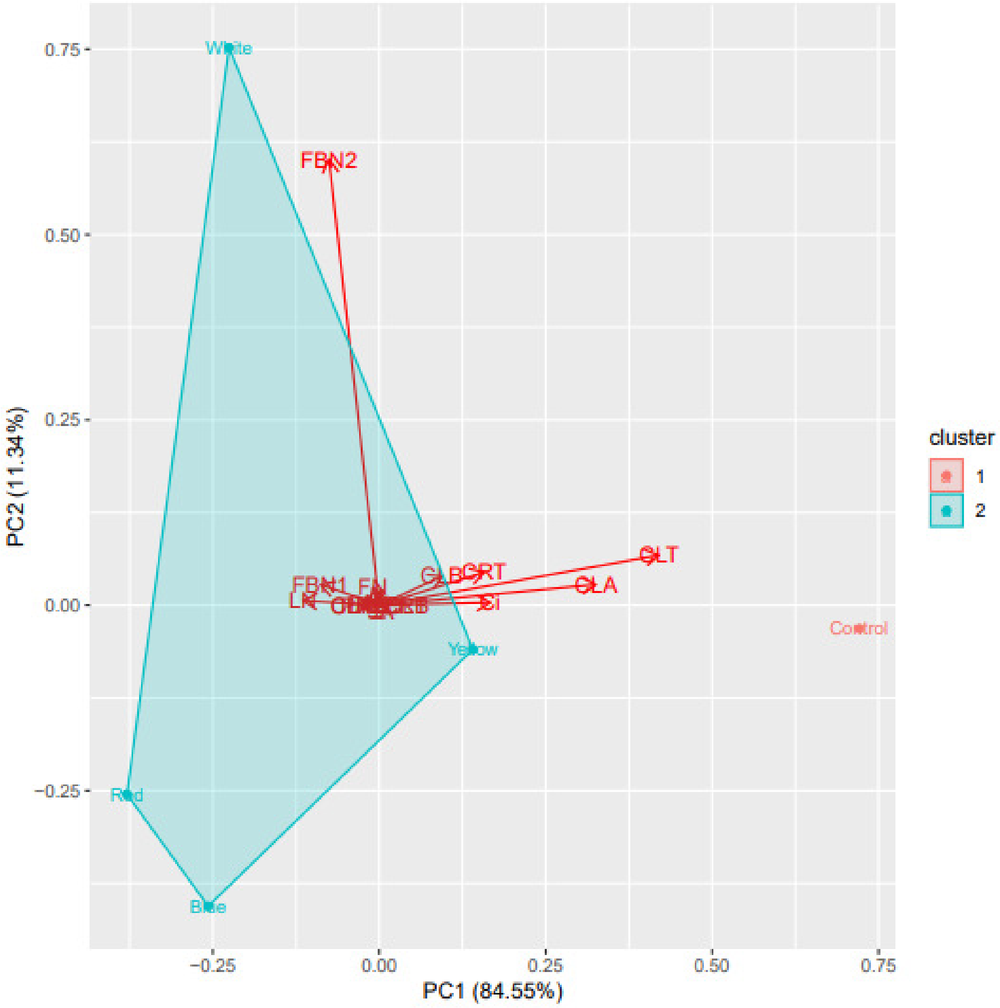

Figure 8. Principal component analysis for the variables plant height at 58 DAS (PH1) and 88 DAS (PH2) (A), number of flower buds at 58 DAS (NFB1) and 88 DAS (NFB2), number of leaves (NL) at 58 DAS, number of flowers (NF) at 88 DAS, number of fruits at 88 DAS (NFR), chlorophyll a (CLA), chlorophyll b (CLB), chlorophyll a/b ratio (CLA CLB), total chlorophyll (CLT), carotenoids (CRT), total chlorophyll/carotenoids ratio (CLT_CRT), internal CO_2 concentration (*Ci*), transpiration rate (*E*), stomatal conductance (*gs*), CO_2 assimilation rate (*A*), water use efficiency (*A_E*) and instantaneous carboxylation efficiency (*A_ Ci*) of the 'pyramid' ornamental pepper (*Capsicum frutescens*) on different colored growing benches

All the wavelengths provided by the different colors positively influenced the visual aspects of the biometric and fruit characteristics of the ornamental pepper (pyramid) plants (Figure 9), essential characteristics for marketing ornamental plants.

A: White **B: Red** **C: Yellow**

D: Dark Blue **E: Control**

Figure 9. Ornamental pepper (Pyramid) plants (*Capsicum frutescens*) on white (A), red (B), yellow (C), dark blue (D) and control (E) growing benches at 88 DAS

Discussion

Photosynthetically active radiation (PAR) is a critical factor influencing the complete development of plants grown in protected environments (Lazzarini *et al.*, 2017; Wang *et al.*, 2021. Variations in PAR can induce changes in the morphophysiological traits of crops (Taiz *et al.*, 2015; Dou *et al.*, 2020). In this study, the use of colored growing benches in a protected cultivation environment resulted in alterations in the morphological development and fruit production of ornamental peppers. These findings align with results observed in other studies, such as colored reflective benches have been shown to affect seedlings of Guaraci Cumari do Pará pepper (*Capsicum chinense*) (Bortolheiro *et al.*, 2025), cherry tomato (*Solanum lycopersicum* var. cerasiforme) (Campos *et al.*, 2023), basil (*Ocimum basilicum*) (Cavalcante *et al.*, 2021), rocket (*Eruca sativa*) (Cavalcante *et al.*, 2024a), *Zinnia elegans* (Cavalcante *et al.*, 2024b), cabbage (*Brassica oleracea* var. Sabellica L.) (Dantas *et al.*, 2025), and chicory (*Cichorium intybus*) (Araújo *et al.*, 2024).

It was found that the wavelength promoted by the different colors positively influences the growth and fruit production of the ornamental pepper (pyramid), resulting in larger plants with more flower buds and fruit. These growth and production qualities observed for the ornamental pepper ('Pyramid'), using colors on the growing bench, are associated with the amount of photosynthetically active radiation reflected by the white, yellow, and red colors and the quality of the light. The red (Cavalcante *et al.*, 2021; Campos *et al.*, 2023; Cavalcante *et al.*, 2024a; Araújo *et al.*, 2024; Dantas *et al.*, 2025) and white, yellow, and dark blue (Araújo *et* *al.*, 2024; Dantas *et al.*, 2025) colors, with their specific wavelengths, increase the plant's energy efficiency, promoting quality and greater production.

The reflectance of the colors white, yellow, red, and blue results in light supplementation for the ornamental pepper ('Pyramid') plants, which led to increase in height, number of leaves, number of flower buds, and number of fruits in this study (Figures 3 and 4), due to greater use of the irradiance incident within the protected environment, leading to an increase in the metabolites accumulated in the pepper plants (Sulistyowati *et al.*, 2023). The positive effects of reflected or supplemented solar radiation can vary depending on the plant species. Red and blue wavelengths can influence the biosynthesis of secondary compounds in plants, playing a key role in the crop antioxidant system, chlorophyll synthesis, and gas exchange (Dou *et al.*, 2020). Blue wavelengths stimulate various physiological processes, such as stomata opening, photosynthesis, and phototropism (Lazzarini *et al.*, 2017), however, this changes were not observed in the present study. Light supplementation by white color, which combines several wavelengths of all colors, increases plant growth (Lazzarini *et al.*, 2017).

White, yellow, blue and red growing benches improved the number of fruit, the same was observed in red color (Campos *et al.*, 2023), blue, yellow, and white colors increased the number of fruits; the red (Cavalcante *et al.*, 2024a), blue (Bortolheiro *et al.*, 2025), white, and yellow colors increased the growth in height and all the colors provided a greater number of leaves and fresh and dry matter (Araújo *et al.*, 2024; Dantas *et al.*, 2025) of the pepper plants, which take advantage of the availability in quantity and quality of the wavelengths of the different colors to better synthesize and convert them into photoassimilates.

The stimulus provided by different sources of reflectance and/or supplementation can be variable depending on the crop analyzed (Khoramtabrizi *et al.*, 2020; Cavalcante *et al.*, 2024a). Therefore, just as light supplementation has positive effects, there can be negative effects, depending on the species. The white color of the growing bench for *Capsicum chinense* seedlings promoted lower growth in diameter, number of leaves, and dry mass, as excess light or excess of one wavelength was harmful and reduced growth, as seen in *Brassica oleracea* var. Sabellica L. (Dou *et al.*, 2020).

Despite the stimulus and increase in quality observed in the morphology and production of the ornamental pepper ('Pyramid') plants in this study, an increase in chlorophyll and carotenoid content was not observed in these plants with the use of the colored growing benches compared to the control (Figure 5), unlike other species, in which *Capsicum chinense* seedlings showed increase in chlorophyll a, b, total and carotenoid content on dark blue, red, and yellow benches (Bortolheiro *et al.*, 2025), in *Zinnia elegans* higher relative chlorophyll content in white bench (Cavalcante *et al.*, 2024b), in *Ocimum basilicum* higher relative chlorophyll content in white and red benches (Cavalcante *et al.*, 2021), in *Cichorium intybus* higher total chlorophyll content in red benches and higher carotenoid content in blue benches (Araújo *et al.*, 2024) and in *Brassica oleracea* var. Sabellica L. in blue and yellow benches, has higher chlorophyll a, b, and total and carotenoid content (Dantas *et al.*, 2025).

Plants have to adapt to the growing environment and different light intensities, chlorophylls and carotenoids can be degraded in environments with excess light (Streit *et al.*, 2005). The use of colored benches altered the reflected photosynthetically active radiation (Figure 2), which may have caused an excess of a single type of reflected radiation according to the color of the bench and this could cause the reduction in chlorophylls and carotenoids, which was observed in the present study for colored benches (Figure 5), and consequently harm the photosynthetic activity of plants, as also observed in the present study (Figure 6).

Photosynthetic activities (gas exchange) of the ornamental pepper (pyramid) plants in this study were not positively influenced by colored growing benches, similar to what was found in *Cichorium intybus* (Araújo *et al.*, 2024). However, this is different from other leafy vegetable species, such as *Eruca sativa*, where there was an increase in internal CO_2 concentration, stomatal conductance, transpiration rate, and net CO_2 assimilation rate, which led to a greater number of leaves, leaf area, and leaf dry weight (Cavalcante *et al.*, 2024a). In *Brassica oleracea* var. Sabellica L., the higher net CO_2 assimilation rate on the white, red, and yellow growing benches led to a greater number of leaves and fresh and dry matter (Dantas *et al.*, 2025).

Although there was no increase in the photosynthetic activity of the plants, an increase in the morphological and production characteristics was observed, indicating the adaptation of the plant to the environment and the complexity of the plant's responses to changes in the environment, such as the use of colored benches. Plant responses may vary depending on changes in the environment in which the plant is inserted, which leads to prioritizing one process or another (Zheng *et al.*, 2023). In the present study, plants prioritized growth, which was converted into greater production in the detriment of gas exchange and chlorophyll. Changes in the environment can stimulate greater production of hormones in plants, hormones such as strigogalactones, GABA, auxins can stimulate plant growth (Zheng *et al.*, 2023).

This study has shown that using colored growing benches is an alternative that helps plants capture more photosynthetically active radiation, both in quantity and quality and consequently promotes greater development and increased yield characteristics.

Conclusions

The use of colored benches improved quality of ornamental pepper. The colored growing benches, mainly white, yellow, and red, increased the supply of photosynthetically active radiation, except for the blue color, with radiation similar to the control. The colored growing benches promoted ornamental pepper plants with higher biometric quality than the control growing bench, in terms of plant height, number of flowers, number of flowers buds, and number of fruits, essential aspects in the marketing of ornamental plants.

Authors' Contributions

Conceptualization: MMD, GPVS, EC, FFSB, EPV. Methodology: MMD, GPVS, EC, PHRM, RCBN, FFSB. Investigation: MMD, GPVS, EC, PHRM, RCBN, FPAPB. Resources: GHCV, EC, FFSB, EPV. Data curation: MMD, GPVS, EC, FFSB, EPV, FPAPB. Writing-original draft: MMD, GPVS, EC, FFSB, PHRM, RCBN, FPAPB. Writing-review & editing: MMD, GPVS, EC, FFSB, FPAPB, EPV. Project administration: FFSB, EC, GHCV. Funding acquisition: FFSB, EC, GHCV.

All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements

Authors thank Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado do Mato Grosso do Sul (FUNDECT); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Conflict of Interests

Authors declare that there are no conflicts of interest related to this article.

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 10:51-66. *https://doi.org/10.22059/ijhst.2023.353706.609*

Araújo TAN, Costa E, Dantas T, Binotti FFS, Vendruscolo EP, Vieira GHC, … Andrade LHC (2024). Growth and bioactive compounds of baby-leaf chicory on colored cultivation benches with different wavelengths. Chilean Journal of Agricultural Research 84:653-662. *https://doi.org/10.4067/s0718-58392024000500653*

Bortolheiro FPAP, Silva KGP, Silva GPV, Martins MB, Costa E, Vendruscolo EP, … Vieira GHC (2025). Photosynthetic pigments and growth of guaraci cumari do pará pepper *Capsicum chinense* Jacq. Seedlings on growth benches with different color wavelengths. International Journal of Horticultural Science and Technology 123:365-374. *https://doi.org/10.22059/ijhst.2024.372767.778*

Campos RS, Costa E, Cavalcante DF, Freitas RA, Binotti FFS (2023). Ornamental cherry tomatoes in different protected environments and reflector materials in cultivation Bench. Revista Caatinga 361:09-20. *https://doi.org/10.1590/1983-21252023v36n102rc*

Cavalcante DF, Garcia AA, Vendruscolo EP, Seron CC, Costa E, Bastos FEA, … Seleguini A (2024a). Reflector materials on benches act as supplementary sources of light in rucola cultivation. Comunicata Scientiae 15:e4046. *https://doi.org/10.14295/cs.v15.4046*

Cavalcante DF, Vendruscolo EP, Bastos FEA, Bortolheiro FPAP, Costa E, Binotti FFS, Ribeiro BLQ (2024b). Substrate based on agro-industrial waste and color of cultivation benches influence the production of *Zinnia elegans*. Ornamental Horticulture 30:e242726. *https://doi.org/10.1590/2447-536X.v30.e242726*

Cavalcante DF, Vendruscolo EP, Seleguini A, Seron CC, Costa E, Pires LL (2021). Reflective benches for improving lighting in residential basil cultivation. Advances in Horticultural Science 354:342-349. *https://doi.org/10.36253/ahsc-10983*

Cisternas-Jamet J, Salvatierra-Martínez R, Vega-Gálvez A, Stoll A, Uribe E, Goñi MG (2020). Biochemical composition as a function of fruit maturity stage of bell pepper *Capsicum annum* inoculated with *Bacillus amyloliquefaciens*. Scientia Horticulturae 263:109107. *https://doi.org/10.1016/j.scienta.2019.109107*

Dantas T, Costa E, Scalon SPQ, Araújo TAN, Binotti FFS, Vendruscolo EP, … 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 13:21381. *https://doi.org/10.1038/s41598-023-48266-3*

Dou H, Niu G, Gu M, Masabni J (2020). Morphological and physiological responses in basil and brassica species to different proportions of red, blue, and green wavelengths in indoor vertical farming. Journal of the American Society for Horticultural Science 1454:267-278. *https://doi.org/10.21273/JASHS04927-20*

Holopainen JK, Kivimäenpää M, Julkunen-Tiitto R (2018). New light for phytochemicals. Trends in Biotechnology 36:7-10. *https://doi.org/10.1016/j.tibtech.2017.08.009*

Jiménez-Viveros Y, Núñez-Palenius HG, Fierros-Romero G, Valiente-Banuet JI (2023). modification of light characteristics affect the phytochemical profile of peppers. Horticulturae 9:72. *https://doi.org/10.3390/horticulturae9010072*

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*

Khoramtabrizi M, Aliniaeifard S, Chegini G (2020). Effects of different artificial light spectra on growth of lettuce in a continuous light plant factory system. Acta Horticulturae 1271:101-106. *https://doi.org/10.17660/ActaHortic.2020.1271.14*

Lazzarini LES, Pacheco FV, Silva ST, Coelho AD, Medeiros APR, Bertolucci SKV, … Soares JDR (2017). Use of light-emitting diode LED in the physiology of cultivated plants–review. Scientia Agraria Paranaensis 16:137-144.

Lefsrud MG, Kopsell DA, Kopsell DE, Curran-Celentano J (2006). Irradiance levels affect growth parameters and carotenoid pigments in kale and spinach grown in a controlled environment. Physiologia Plantarum 127:624-631. *https://doi.org/10.1111/j.1399-3054.2006.00692.x*

Lichtenthaler HK (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. Methods in Enzymology 148:350-382. *https://doi.org/10.1016/0076-68798748036-1*

Mendes NS, Gonçalves ECBA (2020). The role of bioactive components found in peppers. Trends in Food Science, Technology 99:229-243. *https://doi.org/10.1016/j.tifs.2020.02.032*

Nornberg ML, Pinheiro PN, Nascimento TC, Fernandes AS, Jacob-Lopes E, Zepka LQ (2021). Carotenoids profile of *Desertifilum* sp. in mixotrophic conditions. Brazilian Journal of Development 7:33017-33029. *https://doi.org/10.34117/bjdv7n3-835*

R Core Team (2023). R: A language and environment for statistical computing. (Version 4.2.2). R Foundation for Statistical Computing.

Santos HSN, Rocha MS, Delvaux Júnior NA, Santos Neto JA, Martins MJ, Alves RM, … Pimenta S (2023). Pulverização de água ozonizada no controle de pulgões em pimenta ornamental. Contribuciones a Las Ciencias Sociales 1610:24630-24641. *https://doi.org/10.55905/revconv.16n.10-347*

Streit NM, Canterle LP, Canto MW, Hecktheuer LHH (2005). The chlorophylls. Ciência Rural 35:748-755. *https://doi.org/10.1590/S0103-84782005000300043*

Sulistyowati Y, Wahyuni Hartati N, Kim J, Cho E, Seskar M, Raskin I, Sudarmonowati E (2023). Effect of various LED light on the growth and reproductive of in vitro-derived Indonesian chili pepper *Capsicum annum* Kopay and Laris varieties. IOP Conference Series: Earth and Environmental Science 1255:012047. *https://doi.org/10.1088/1755-1315/1255/1/012047*

Taiz L, Zeiger E, Moller I M, Murphy A (2015). Plant Physiology and Development. 6th Edition, Sinauer Associates, Sunderland, Massachusetts, United Sates of America.

Villalobos FJ, Fereres E (Eds) (2016). Principles of agronomy for sustainable agriculture. Springer, New York, United States of America. *https://link.springer.com/book/10.1007/978-3-319-46116-8*

Wang C, Du J, Lui Y, Chow D (2021). A climate-based analysis of photosynthetically active radiation availability in large-scale greenhouse across China. Journal of Cleaner Production 315:127901. *https://doi.org/10.1016/J.JCLEPRO.2021.127901*

Xiao Z, Rausch SR, Luo Y, Sun J, Yu L, Wang Q, … Stommel JR (2019). Microgreens of Brassicaceae: Genetic diversity of phytochemical concentrations and antioxidant capacity. LWT 101:731-737. *https://doi.org/10.1016/j.lwt.2018.10.076*

Zheng Y, Wang X, Cui X, Wang K, Wang Y, He Y (2023). Phytohormones regulate the abiotic stress: An overview of physiological, biochemical, and molecular responses in horticultural crops. Frontiers in Plant Science 13:1095363. *https://doi.org/10.3389/fpls.2022.1095363*