Light sources indoor benefit the growth and development of pepper cultivars

Marcos Vinícius Marques Pinheiro[1], *Maria Inês Diel*[2*], *Oscar Valeriano Sanchéz Valera*[3], *Leonardo Antonio Thiesen*[4], *Anderson Rafael Webler*[5], *Guilherme Masarro-Araujo*[5], *Diéssica Letícia Junges*[5], *Tainara Gris*[6], *Denise Schmidt*[5]

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ABSTRACT

Light is a determining factor in plant morphophysiology, as it influences the growth and development of agricultural crops. Thus, the objective was to investigate the effects of light sources on the growth and development of "biquinho" pepper cultivars. The experiment was performed in two stages (Exp1 and Exp2), evaluating two cultivars (BRS Moema; Airetama biquinho) in five light sources (white LEDs, red LEDs, blue LEDs, red/blue LEDs, and fluorescent lamps). In Exp1 the plants were kept in a controlled condition, with a completely randomized design, in a 2x5 factorial scheme (cultivars x light sources) until 76 days after emergence (DAE), in which growth variables and photosynthetic pigments were evaluated. In Exp2, the plants were removed from the above conditions and transplanted in pots, being kept in greenhouse for more 76 DAE. At 152 DAE, the same variables as Exp1 were evaluated, as well as gain of shoot fresh and dry mass, and gain of root fresh and dry mass. In both experiments, growth variables were affected by cultivar and the light sources, however, the behavior did not follow the same trend for all variables, indicating that the light quality influences the growth of the crops, and impacting during greenhouse conditions.

Keywords: *Capsicum chinense*; light quality; light-emitting diodes (LEDs); photosynthetic pigments.

INTRODUCTION

The study of the physiology of plants and their behavior in different environments allowed humans to both select plants and modify their environment to obtain greater productivity and other desired characteristics. However, environmental factors, ie water availability, nutrients and the quality and quantity of light are important for plant growth and development (Guo *et al.,* 2016; Zhang *et al.,* 2019).

Among these environmental factors, light stands out as an important regulator of plant development, morphogenesis and physiology, and the quality provided may be able to influence plant productivity. The visible light range, between 400 and 700 nm, is known as photosynthetically active radiation, with the bands of red (600 to 700 nm) and blue (400 to 500 nm) being the ones that most affect photosynthesis, because the molecules of chlorophyll absorb wavelengths in these bands, while the others are usually reflected or transmitted.

Recent innovations in plant growth lighting, particularly through light-emitting diode (LED) technology, allow

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[1] Universidade Estadual do Maranhão, São Luís, Maranhão, Brazil. macvini@gmail.com
[2] Universidade Federal do Pampa, Itaqui, Rio Grande do Sul, Brazil. mariaines.diel@hotmail.com
[3] Instituto Nacional do México, Instituto Tecnológico Superior de Zongolica, Veracruz, Mexico. oscarvalera@itszongolica.edu.mx
[4] Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil. thiesen07@hotmail.com
[5] Universidade Federal de Santa Maria, Frederico Westphalen, Rio Grande do Sul, Brazil. anderson.webler@gmail.com; guilhermemasarroaraujo@gmail.com; diessicajunges@gmail.com; denise@ufsm.br
[6] Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina, Brazil. tainaragris95@gmail.com
*Corresponding author: mariaines.diel@hotmail.com

for the creation of customized light spectra, bringing spectra into the decision-making process when a grower or researcher is selecting agricultural lighting (Claypool & Lieth, 2020). LEDs have the flexibility to provide specific wavelengths with the possibility of selecting the emission peak that most closely matches the absorption of photoreceptors, and thus faster and more favorable results for researchers and plant producers (Gupta & Jatothu, 2013; Miler *et al.,* 2019). Using light sources based on LEDs it is possible to regulate and control the physiological aspects of plant growth, such as photosynthesis and/or photomorphogenesis (Gupta & Jatothu, 2013).

In addition, the light emitted from the LEDs is an abiotic elicitor capable of being used in plant morphogenesis, as it has high specificity in wavelengths, allowing researchers to eliminate other wavelengths found in white light, and thus study the stimulating them in the architecture of the plant and in the productive responses. The use of light wavelengths promotes different morphogenetic and photosynthetic responses that may vary among plant species (De Hsie *et al.,* 2019), and in terms of plant production, there are only a few applications where a spectrum of pure monochrome light produces good growth results, such as keeping plants compact or retarding plant growth (Miler *et al.,* 2019).

LED lighting technologies for plant cultivation are rapidly evolving, and lamps for indoor cultivation are often designed to optimize their light emissions in the photosynthetically active spectrum (i.e. red and blue), to reduce energetic requirements for satisfactory yield (Pennisi *et al.,* 2020). This technology has been widely used in horticultural facilities in recent years, however, the influence of light quality should be further explored (Yang *et al.,* 2018). Red and blue lights are currently two types of light spectra that have been most studied on plant photobiology (Zhang *et al.,* 2020).

Plants respond differently to each photosynthetic pigment, the quality of light has varying influences on plant growth and development. The red light (660 nm) and the distant red light (730 nm) affect phytochrome, which affects from seed germination to flowering, fruiting and aging (Oren *et al.,* 2021). The blue-violet light (400-490 nm) regulates plant growth through cryptochromes and phototropins, affecting the growth and development of the root system, and plant stem growth (Pedmale *et al.,* 2016). The yellowish-green light (490-550 nm) is also photosynthetically active radiation (Lin *et al.,* 2020). In *Dendranthema grandiflorum* (chrysanthemum) under red LEDs, increased in height and larger internodes, under blue/red LEDs there was largest fresh weight and greater plant growth, and reduced plant growth kept under blue LEDs (Kim *et al.,* 2004). In *Vaccinium corymbosum* the red light promoted greater rooting and elongation of the stem, and the combinations of blue/red LEDs benefited the accumulation of plant biomass *in vitro* (Hung *et al.,* 2016).

The use of far red inside the canopy of tomato plants resulted in stem elongation, difference in leaf morphology, greater length/width ratio of the leaves, largest leaf area and increase of 7 to 12% in the production of ripe fruits (Zhang *et al.,* 2019). In peppers, the effects of LED lights on growth, yield and fruit quality were tested, with an increase in fruit production, in the dry matter content of the fruits and in the content of fruit-promoting compounds in the fruits (i.e. total phenolic content, carotenoid content and antioxidant activities) (Guo *et al.,* 2016).

In *Capsicum annuum*, plant biomass was reduced when the plants remained under red LEDs in the absence of the blue wavelength, producing characteristics such as greater height and greater mass of the stem, suggesting that the plants require supplementary radiation especially in the blue region for the normal growth and development (Brown *et al.,* 1995). Even with these results, the same authors confirm the physiological and morphological effects of the quality of light, and they can vary according to the species. For cultivars of biquinho pepper (*Capsicum chinense*), light spectra were studied during the seed germination process, concluding that the luminous environment in green, red and far red colors positively influence the germination and the amount of abnormal plants was increased in the dark (Diel *et al.,* 2019). For this species, this is the only report, and it is crucial to study the influence of light source on the morphogenesis and physiology of this culture.

Several studies have revealed the effects of light on the biomass of different species, using LEDs of specific wavelengths. For this, the question remains: which band of the light spectrum can influence the morphogenesis of *Capsicum chinense*? The aim of the study was to evaluate the effects of light sources indoor on the morphogenesis (growth and development) of two cultivars of pepper.

MATERIALS AND METHODS

2.1 Study area and growth conditions

The experiment was carried out at the Federal University of Santa Maria UFSM campus Frederico Westphalen - Rio Grande do Sul, Brazil. The geographical location of this region is 27º22'S, 53º25'O at 480 m of altitude. According to the Köppen classification, the region's climate is Cfa, humid subtropical (Alvares *et al.,* 2013).

For the conduct of the experiment, two steps were performed (Experiment I and II), the first was conducted in a growth room with controlled temperature, humidity and light intensity conditions and the second in a greenhouse.

2.2 Experiment I - Does the light source indoor benefit the vegetative process of biquinho pepper cultivars?

2.2.1 Plant material and propagation

Seeds of two cultivars of "biquinho" pepper, *Capsicum chinense*, (BRS Moema and Airetama Biquinho) were used, characterized by red and yellow fruits when ripe, respectively. The seeds were pre-germinated on Germitex® paper in transparent plastic Gerbox® and kept in a growth chamber (BOD type) at a constant temperature of 25 °C, 12 hours of light and 12 hours of photoperiod with 36 µmol m^{-2} s^{-1} irradiance from two fluorescent lamps ("Luz do Dia Especial", 40 W, Osram®, Brazil). To break the seed dormancy, KNO_3 solution (2%) was added, following the standards of MAPA (2009), and after about 15 days after emergence (DAE), when 50% of the seeds showed root protrusion, they were transplanted into transparent plastic cups (300 mL) filled with Carolina® commercial substrate.

From the transplant to plastic cups, the seedlings were kept in a growth room, with a temperature of 25 ± 2 ºC, a photoperiod of 16 hours of light and eight hours of darkness, with a luminous intensity of 72 µmol m^{-2} s^{-1} from different light sources: four fluorescent lamps ("Luz do Dia Especial", 40 W, Osram®, Brazil); two tube lamps (TECNAL TECLAMP®, Piracicaba, Brazil) of different colors [white LEDs, red LEDs (660 nm), blue LEDs (450 nm), red/blue LEDs (660 and 450 nm, with a ratio of 60 and 40%, respectively).

The plants were irrigated manually keeping the humidity constant (to avoid water stress), and the plant nutrition was carried out via fertigation, with nutrient solution (200 g 1000 L^{-1} of HidrogoodFert®, 250 g 1000 L^{-1} of calcium nitrate and 15 g 1000 L^{-1} of iron EDDHA, Yara®), and electrical conductivity of the solution maintained at 600 µS. The plants remained in growth room conditions until the beginning of flowering, which was determined when 50% of the plants in the plot emitted flowers, that is, with 76 DAE.

2.2.2 Experimental design and variables analyzed

The experimental design used was entirely random in a 2 x 5 factorial scheme, with two cultivars of pepper (BRS Moema and Airetama Biquinho) and five light sources (fluorescent lamps, white LEDs, red LEDs, blue LEDs, and red/blue LEDs), totaling ten treatments with four repetitions per treatment, the experimental unit being composed of four plants, totaling 16 plants per treatment.

At 76 DAE and before transplantation (Experiment II) were evaluated: plant height (PH, cm), number of leaves (NL), shoot fresh mass (SFM, g), shoot dry mass (SDM, g), root fresh mass (RFM, g), root dry mass (RDM, g), root volume (RV, mL), root length (RL, cm), leaf area (LA, m²) and photosynthetic pigments [chlorophyll *a* (Chl*a*), chlorophyll *b* (Chl*b*), total chlorophylls (ChlT), carotenoids (Car) and total chlorophyll/carotenoid ratio (ChlT/Car)].

Before transplanting the plants to the pots, half of them were separated for destructive evaluations of Experiment I and the other half for Experiment II, being evaluated at the end of 152 DAE.

The number of leaves and plant height were evaluated from the emission of the first expanded leaf to the first fork in the main stem of the plant. The root volume was calculated immediately after calculating the fresh mass, from the displacement of water in a graduated cylinder after submersion of the root system. The root length was evaluated by measuring the length of the main root (pivoting root).

The leaf area (LA, cm²) was determined using an LA integrator [model Licor LI- 3100 (LI-COR®, Lincoln, Ne, USA)]. For this, all the leaves were separated from the stem of the plants, being passed one by one in the analyzer.

2.3 Experiment II - Mass gains and quality of plants subjected to light source during the vegetative process of cultivars of biquinho pepper

2.3.1 Plant material

At 76 DAE the plants were removed from the growth room conditions and transplanted in black pots (5 L) filled with typical dystrophic Red Latosol soil, and kept in a greenhouse with a metallic structure in the shape of an arch, 3.5 m high, 10 and 20 m wide and long, covered with plastic film 150 microns thick, remaining for another 76 days, with a total of 152 DAE (fruit ripening; 50% of plants with ripe fruit).

The plants were irrigated manually, always maintaining constant humidity to avoid water stress. For this purpose, the same fertigation solution mentioned above was used, remaining until 152 DAE.

2.3.2 Experimental design and variables analyzed

This experiment was conducted in a randomized block design in a 2 x 5 factorial scheme, with two cultivars of biquinho pepper (BRS Moema and Airetama Biquinho) and plants from five light sources (cited in Experiment I), totaling ten treatments with ten repetitions per treatment, and each repetition composed of a plant.

At 152 DAE, were evaluated: plant height (PH, cm), number of leaves (NL), shoot fresh mass (SFM, g), shoot dry mass (SDM, g), root fresh mass (RFM, g), root dry mass (RDM, g), root volume (RV, mL), root length (RL, cm), photosynthetic pigments [chlorophyll *a* (Chl*a*), chlorophyll *b* (Chl*b*), total chlorophylls (ChlT), carotenoids (Car) and total chlorophyll/carotenoid ratio (ChlT/Car)] and fresh fruit mass (FFM, g) and dry fruit mass (DFM, g). The mass gain was calculated as a percentage for SFM, SDM, RFM, SDM shoot fresh mass (SFM, g), shot dry mass (SDM, g), root fresh mass (RFM, g) and shot dry mass (SDM, g), at 76 DAE and 152 DAE (Experiment I and II). That is, during the period between and greenhouse conditions (76 DAE and 152 DAE, respectively), the masses were related, being calculated as a percentage: gain of shoot fresh mass (%, GSFM), gain of shoot dry mass (%, GSDM), gain of root fresh mass (%, GRFM), gain of root dry mass (%, GRDM).

2.3.3 Photosynthetic pigments

To determine photosynthetic pigments (Experiment I and II), chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids, five disks of 5 mm diameter each were obtained from the second green leaf (from the apex to the base) and incubated in glass test tubes containing 5 mL of dimethylsulfoxide (DMSO) saturated with calcium carbonate ($CaCO_3$), kept in the dark at room temperature for 48 hours, following the modified methodology of Santos *et al.* (2008), totaling four repetitions per treatment. After 48 hours of darkness, absorbance was determined using the SPERCORD 50/Plus® spectrophotometer (Analytikjena, Germany) using a 10 mm quartz cuvette. Wellburn (1994) methodology was used to establish wavelength and equations to calculate the concentrations of chlorophylls [*a*, *b*, total (*a* + *b*)] and carotenoids and the unit used was in $\mu g\ cm^{-2}$.

2.4 Statistical analysis

The variables of both experiments (I and II) were subjected to analysis of variance and the treatment means, when significant, were separated by the Tukey test at 5% probability of erro. In addition, based on the desired values of the variables studied, the MGIDI index was used to select the best treatments (Olivoto & Nardino, 2020) and were calculated as follows: $MGIDI_i = [\sum_{j=1}^{f}(\gamma_{ij} - \gamma_j)^2]^{0.5}$, where $MGIDI_i$ is the multi-trait genotype-ideotype distance index for the ith treatment; γ_{ij} is the score of the ith treatment in the j th factor (i = 1; 2; :::; t; j = 1; 2; :::; f), being t and f the number of treatments and factors, respectively; and γ_j is the j th score. Treatments that have the lowest calculated indices are the best. Statistical analyzes were performed with the aid of packages metan (Olivoto & Lúcio, 2020), ggplot2 (Wickham, 2016), ExpDes (Ferreira *et al.*, 2021) available in the R program (R Development Core Team, 2021).

RESULTS

3.1 Experiment I - Light source indoor benefit the vegetative process of biquinho pepper cultivars

From the analysis of variance, there was a significant interaction between cultivars x light sources for the variables PH, NL, SFM, RFM, SDM, RDM and LA. The variables RL and RV were significant only for the cultivars factor, and CR only for light sources. For photosynthetic pigments, there was significant interaction between cultivars x light sources for Chl*a*, Chl*b*, ChlT, Car, ChlT/Car.

The growth variables were affected by both the cultivar and the light sources, in the first stage of the experiment (Figure 1). For the PH variable, the cultivar BRS Moema was superior under blue (15.5 cm) and red LEDs (11.37 cm) but obtained lower averages than Airetama in the fluorescent light source (8.21 cm) (Figure 1A). The same pattern occurred for the variables SFM and SDM (Figure 1C, 1D , respectively). BRS Moema, when kept under LEDs, also obtained higher NL values except for the fluorescent light source, where NL was higher for the cultivar Airetama (Figure 1B). Differently, RDM presented another behavior when compared to the other variables, with higher averages in the cv. Airetama when grown under Blue LEDs (Figure 1F). For the RFM variable, the inferior performance was observed for the BRS Moema cultivar grown under white LEDs (Figure 1E).

For the variable RL, the cultivar Airetama had a longer root length when grown under white LEDs (Figure 2A), and shorter when the plants remained under fluorescent and red LEDs (Figure 2C), the same being observed for the variable RV (Figure 2B).

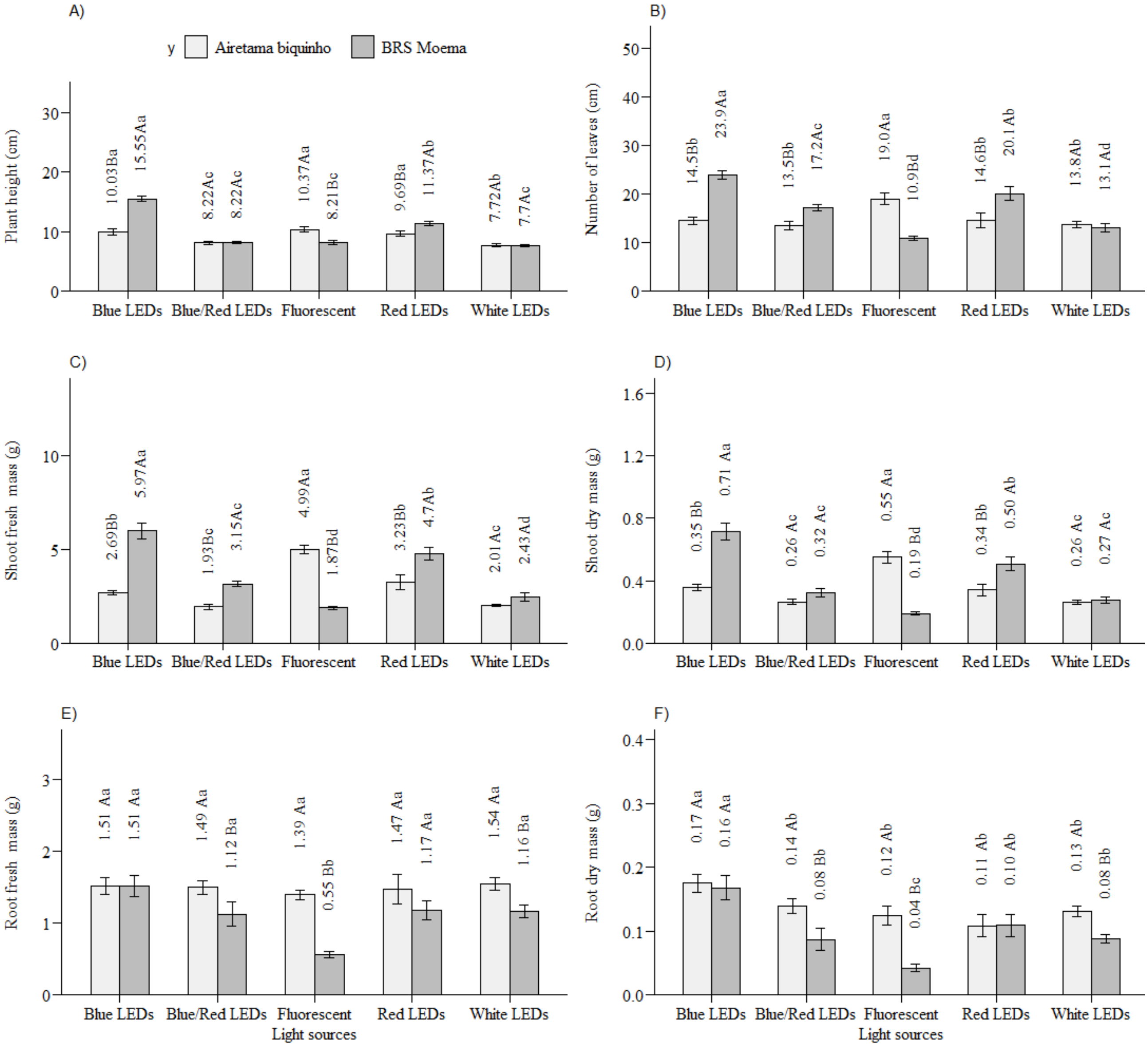

Figure 1: Means of growth variables of biquinho pepper cultivars under different light sources in experiment I: A) plant height (PH, cm), B) number of leaves (NL), C) shoot fresh mass (SFM, g), D) shoot dry mass (RFM, g), E) root fresh mass (SDM, g), F) root dry mass (RDM, g). Lower case letters differ in light sources and upper-case letters differ in cultivars by Tukey's test, at 5% significance.

The cultivar BRS Moema showed superior results of LA when cultivated under blue LEDs and red LEDs. The cultivar Airetama performed better under fluorescent light, while both cultivars showed low performance under the light sources blue/red LEDs and white LEDs (Figure 3A). For chlorophyll *a* (Chl*a*), the cultivar BRS Moema obtained superior results when cultivated under blue LEDs and blue/red LEDs, and inferior performance under fluorescent light, in which the cultivar Airetama obtained superior results (Figure 3B). BRS Moema presented superior results of chlorophyll *b* (Chl*b*) under blue LEDs when compared to Airetama, in the other light sources studied, the two cultivars did not present significant differences. The cultivar Airetama did not differ in any of the light sources, while the cultivar BRS Moema obtained a higher Chl*b* content in the blue light source (Figure 3C). Carotenoids showed significant differences between cultivars in the blue/red LED light source, in which BRS Moema was superior to Airetama, and when kept under fluorescent light, the Airetama cultivar was superior to BRS Moema. It was also observed in the light sources in each cultivar, with BRS Moema being superior under blue/red LEDs and Airetama under fluorescent (Figure 3D).

For the variable ChlT, among the cultivars, BRS Moema was significantly superior to Airetama in the blue and blue/red LED light sources, while the cultivar Airetama was superior to BRS Moema in the fluorescent light source, in which it had superior performance when comparing with all the other light sources studied. BRS Moema had a similar performance when grown under blue, red and blue/red LEDs (Figure 3E). The ChlT/Car ratio showed significant differences between cultivars only under blue LEDs, while within each BRS Moema cultivar it presented a higher ChlT/Car ratio under blue LEDs, and Airetama did not show significant differences between light sources (Figure 3F).

By using the multi-trait index (MGIDI), we selected the 2 best treatments (20%) being T3 (Airetama biquinho and fluorescent light) and T6 (BRS Moema and Blue LEDs), showing the difference in the response of the cultivars in relation to the type of light to which it was submitted (Figure 7A). The two treatments were selected with 90% of the variables with desired values, and only the RV variable did not have the desired selection (SD = -2,35%). Thus, we can say that treatments T3 (Airetama biquinho and fluorescent light) and T6 (BRS Moema and blue LEDs) had a good performance in all analyzed variables, except for RV.

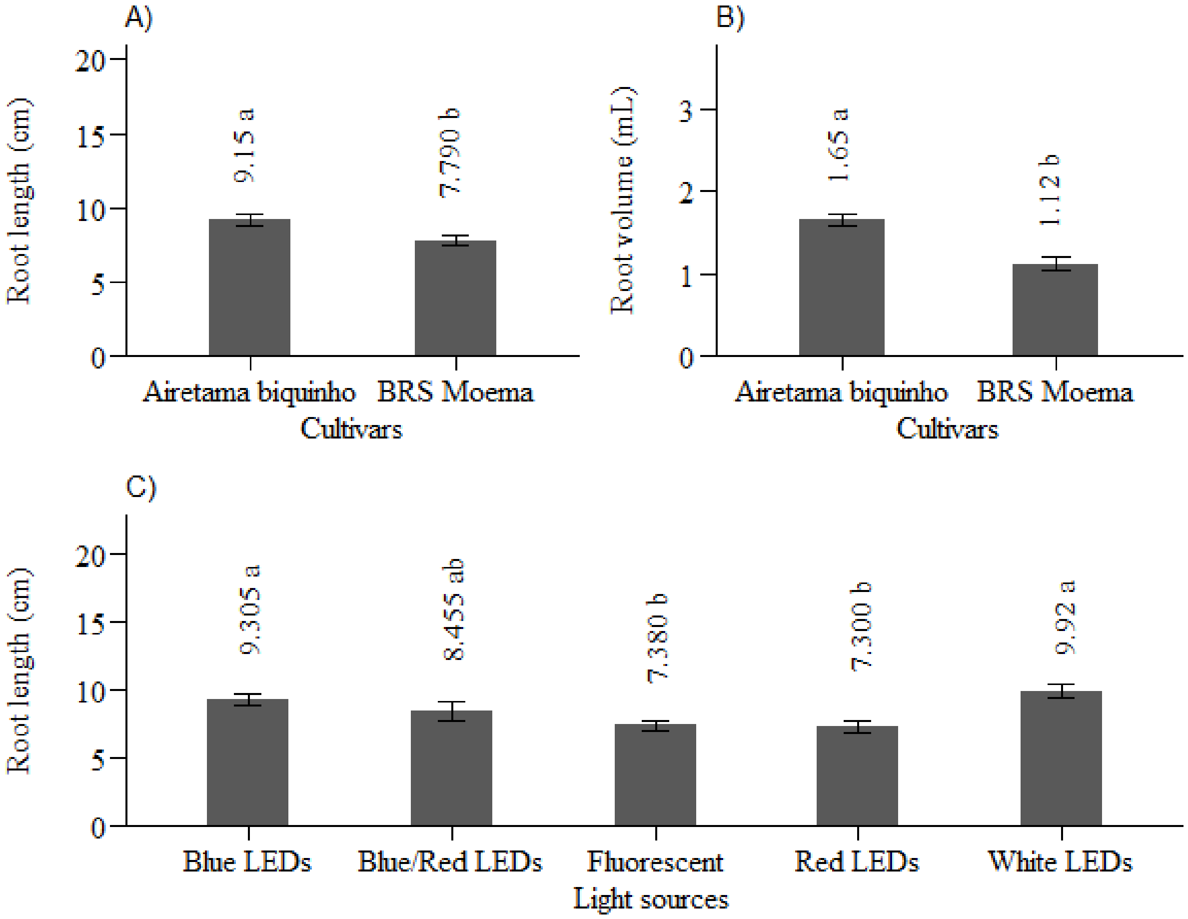

Figure 2: Growth variables (A, C) root length (RL, cm) and (B) root volume (RV, mL) as a function of biquinho pepper cultivars under different light sources in growing room. Lower case letters differ by Tukey's test, at 5% significance.

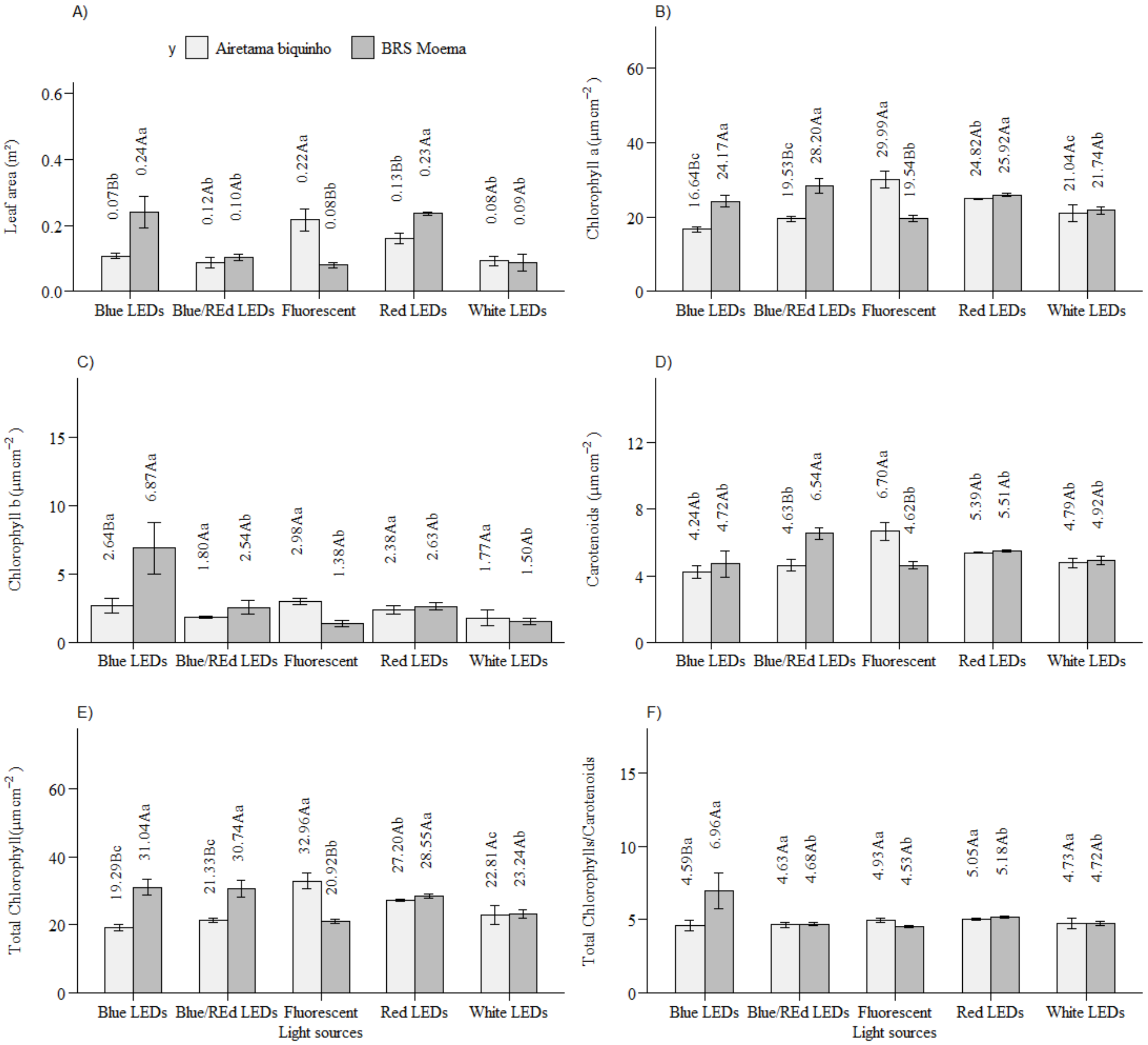

Figure 3: (A) leaf area (LA, m²), (B) chlorophyll *a* (Chl*a*, μm cm^{-2}), (C) chlorophyll *b* (Chl*b*, μm cm^{-2}), (D) carotenoids (CAR, μm cm^{-2}), (E) total chlorophyll content (ChlT, μm cm^{-2}), and F) total chlorophyll/carotenoid ratio (ChlT/Car) of biquinho pepper cultivars grown under different light sources in growing room. Lower case letters differ in light sources and upper-case letters differ in cultivars according to the Tukey's test, at 5% significance.

3.2 Experiment II - Mass gains and quality of plants subjected to light sources during the vegetative process of cultivars of biquinho pepper

From the analysis of variance, it was possible to observe that there was interaction between cultivars x light sources for the growth variables RV, SFM, RSM, RDM. For PH, NL, SDM and RL there was no significant difference. For photosynthetic pigments, there was interaction between cultivars x light sources for the variables Chl*a*, ChlT and Car, whereas for Chl*b* and ChlT/Car ratio there was no significant effect. For the variables of mass gain (GSFM, GSDM, GRFM, GRDM) there was a significant interaction between cultivar x light sources.

The variable RV, after transplanting the seedlings to pots kept inside the greenhouse, the behavior of the cultivar Airetama was superior to BRS Moema when grown under blue LEDs and red LEDs. In the other light sources, the cultivars did not differ significantly. For each cultivar, Airetama showed superior results when kept under blue LEDs and red LEDs, and the BRS Moema cultivar showed no significant differences for light sources (Figure 4A).

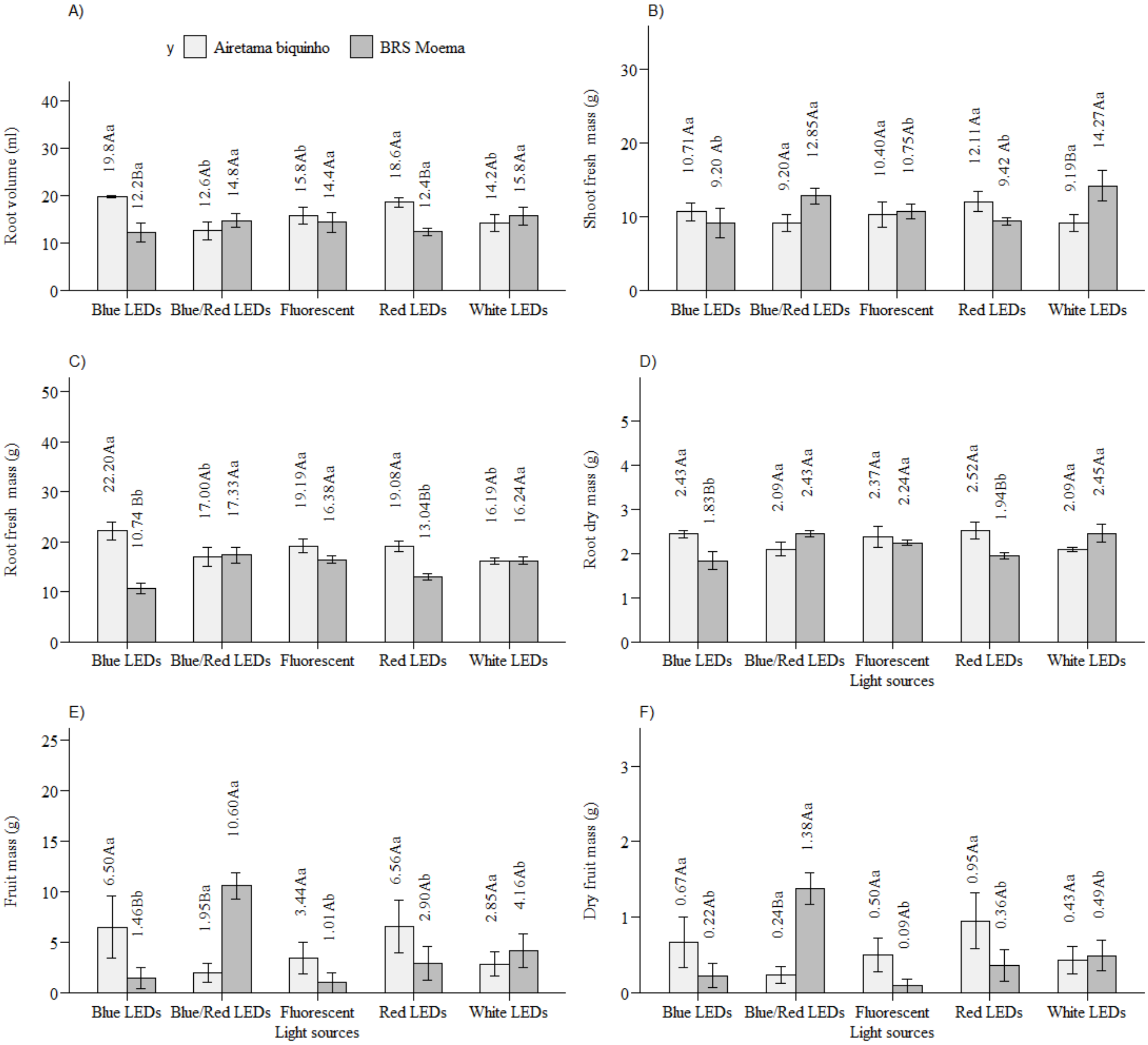

Figure 4: (A) root volume (RV, ml), (B) shoot fress mass (SFM, g), (C) root fresh mass (g), (RFM, D) root dry mass (RDM, g), E) fresh fruit mass (FFM, g) and F) dry fruit mass (DFM, g).of piquet pepper cultivars at 152 DAE in greenhouse. Lower case letters differ in light sources and upper-case letters differ in cultivars according to the Tukey test, at 5% significance.

As for photosynthetic pigments, contrary to what was observed in Experiment I, lower levels of Chl*a* were observed for the BRS Moema cultivar when comparing Airetama under blue LEDs, however the fluorescent light continued to be the one with the lowest Chl*a* values of the BRS Moema cultivar (Figure 5A). For ChlT, among cultivars, different from experiment I, Airetama was significantly superior to BRS Moema in blue LEDs and under fluorescent lamps, while the cultivar BRS Moema was significantly superior to Airetama when kept under red LEDs. Within each cultivar, BRS Moema showed higher ChlT content when the plants were under red and blue/red LEDs. Under blue LEDs, Airetama showed superior performance (Figure 5B). There were significant differences between cultivars for carotenoids, that is, the cultivar Airetama when grown under blue LEDs and fluorescent lamps was superior to BRS Moema, while the latter was significantly superior under red LEDs. Within each cultivar, this variable followed the same trend found for the ChlT variable (Figure 5C). Analyzing the results obtained, we can infer that each cultivar has different characteristics regarding the production of photosynthetic pigments and in relation to each light source.

The mass gain was significant for all treatments (light sources x cultivar), for 76 days passed from the initial to the final evaluation. For GSFM, the lowest mass gain of the cultivar Airetama was observed in the fluorescent light source (101.4%), while for the cultivar BRS Moema the lowest mass gains were observed under blue LEDs (57.3%) (Figure 6A). For GSFM, the cultivar Airetama had no differences between the light sources, while for the cultivar BRS Moema higher values were observed when they were under fluorescent and white LEDs (1338.3 and 1240.1% respectively). Another important factor was observed for the fluorescent source, which showed low GSDM for the cultivar Airetama (332.6%), while for BRS Moema it was superior (Figure 6B).

For GRFM, the cultivar Airetama did not differ between the light sources evaluated, while for the cultivar BRS Moema, when they were subjected to fluorescent sources, it presented the greatest gains compared to LEDs (2578.3%). In comparison to cultivars within each light source, the differences were also related to gains in cultivation under fluorescent (Figure 6C). The same trend was observed for the GRDM variable, in which the greatest gains were achieved under fluorescent lamps for the cultivar BRS Moema (5213.6%) (Figure 6D).

Regarding the multi-trait index (MGIDI), as in experiment I, the 2 best treatments were also selected (20%) being T1 (Airetama biquinho and blue LEDs) and T3 (Airetama biquinho and fluorescent light), showing the difference in the response of the light used (Figure 7B). The two treatments were selected with 60% of the variables with desired values, and the variables RL, NL, SFM and SDM did not have the desired selection (SD = -5.3%, -9.57%, -2.37%, and -0.56%, respectively). Thus, we can say that treatments T1 (Airetama biquinho and blue LEDs) and T3 (Airetama biquinho and fluorescent light) had a good performance in most of the variables analyzed.

DISCUSSION

This is the first report on the use of light source in the cultivation of *Capsicum chinense* cultivars kept under controlled conditions (Experiment I) and the impact of these on the growth and development of plants in greenhouse cultivation (Experiment II) to infer about the increment and gain of the plants in those conditions.

For most of the variables analyzed, there was an interaction between cultivars x light sources evaluated in the study. It is known that pepper genotypes can respond differently to environmental stimuli, and depending on the environment, they can produce, for example, different amounts of capsaicinoids and have differences in development (Jeeatid *et al.,* 2018).

The cultivars showed different responses to the light sources in which they were submitted. For example, the plant height (PH) of the cultivar BRS Moema was higher when they were associated with blue LEDs and red LEDs. The spectrum of blue and red light also impacted the height of petunia flowers, due to the elongation of the stem, due to the blue light stimulating the production of gibberellins, and thus causing changes in height (Fukuda *et al.,* 2016). However, the wavelengths in blue and red can positively or negatively affect the growth and development of the species, and this is because these wavelengths are responsible for the activation of different genetic expressions in plants (Jeeatid *et al.,* 2018).

For growth variables, plants from cultivar BRS Moema showed superior results when grown under monocromatics blue or red LEDs. In contrast, the cultivar Airetama showed greater growth when cultivated under a source of fluorescent light and white LEDs; this reveals that the responses between genotypes of the same species may be different (Jeeatid *et al.,* 2018), and also demonstrated by MGIDI in Experiment I. Fluorescent lamps commonly applied, generally lack a wavelength in red, which is very important for the development of plants, for example in stem elongation and phytochrome activity, while these lamps emit a lot in the green and yellow light spectra, which are less efficient for plants (Miler *et al.,* 2019). In *Capsicum annuum*, a broad spectrum including red, green, and blue wavelengths resulted in the highest shoot dry weight and plant compactness, and under monochromatic blue LEDs, these authors observed a reduced leaf area under blue LEDs (Claypool & Lieth, 2020); differently from the present work, suggesting that this may be a species-specific response.

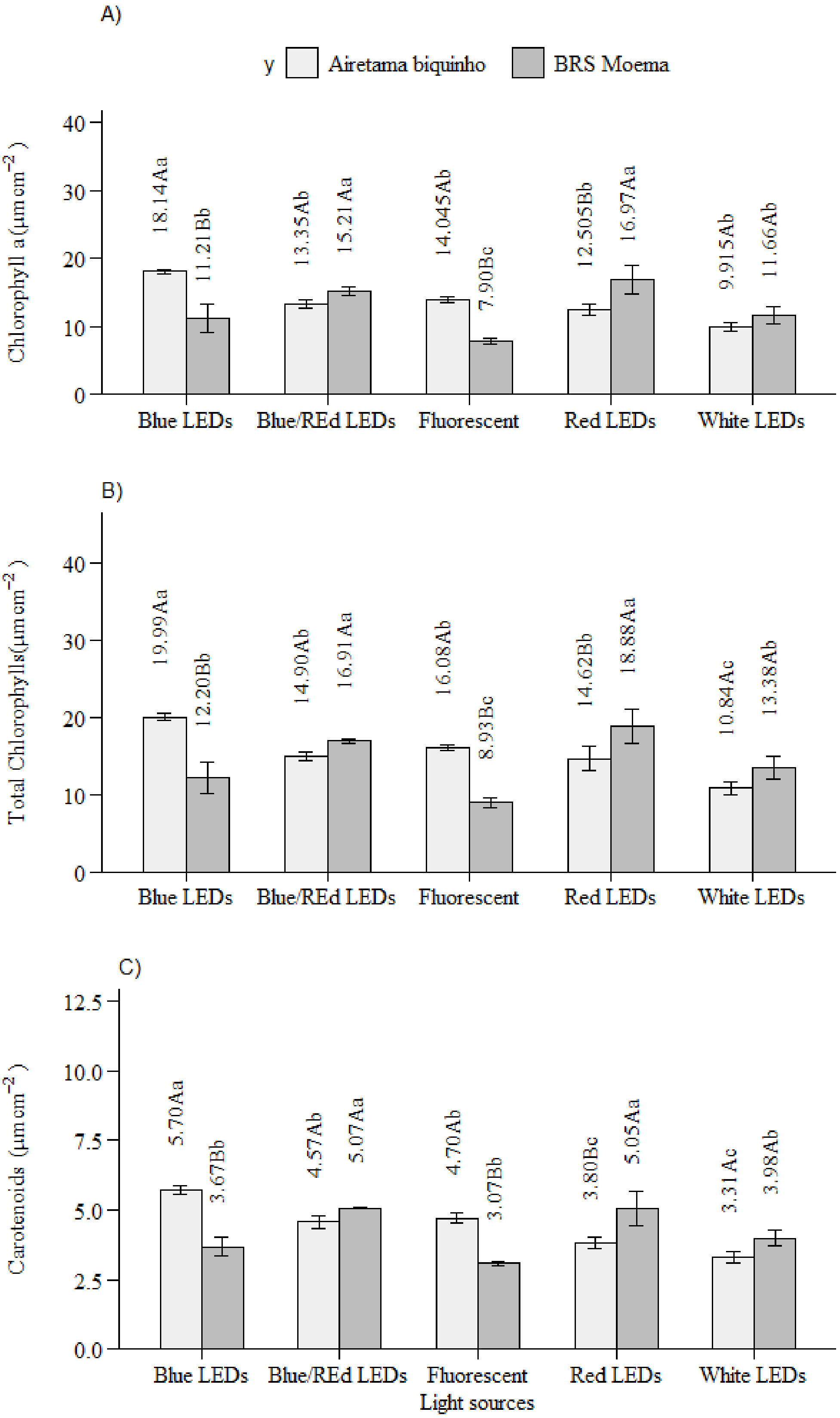

Figure 5: (A) chlorophyll *a* (Chl*a*, µm cm^{-2}), B) total chlorophyll (ChlT, µm cm^{-2}), C) carotenoids (Car, µm cm^{-2}) from biquinho pepper cultivars grown at 152 DAE in greenhouse. Lower case letters differ in light sources and upper-case letters differ in cultivars according to the Tukey's test, at 5% significance.

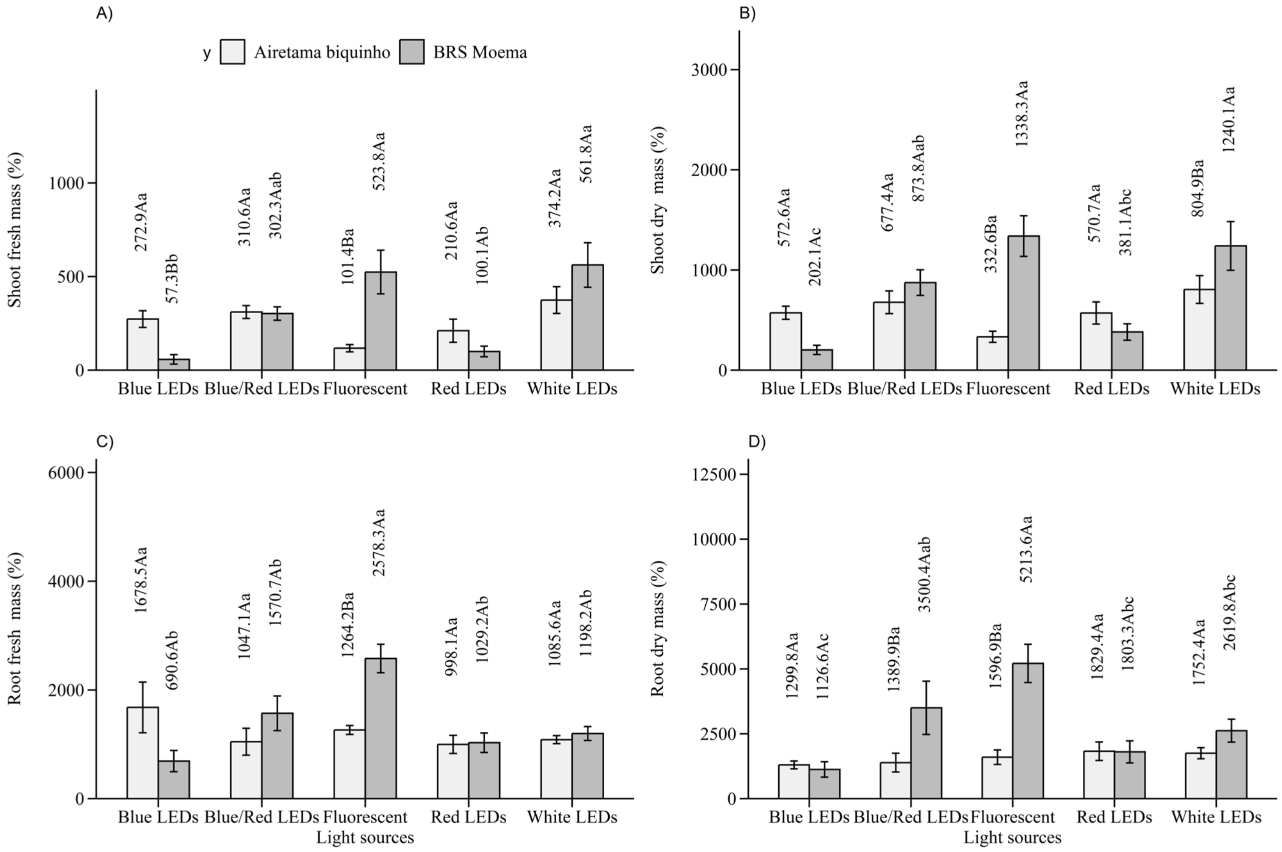

Figure 6: Mass gain as a percentage of 76 DAE to 152 DAE for (A) gain of shoot fresh mass (GSFM, %), (B) gain of shoot dry mass (GSDM, %), (C) gain of root fresh mass (GRFM, %) and (D) gain of root dry mass (GRDM, %) for Airetama and BRS Moema cultivars at 152 DAE in greenhouse. Lower case letters differ in light sources and upper-case letters differ in cultivars according to the Tukey's test, at 5% significance.

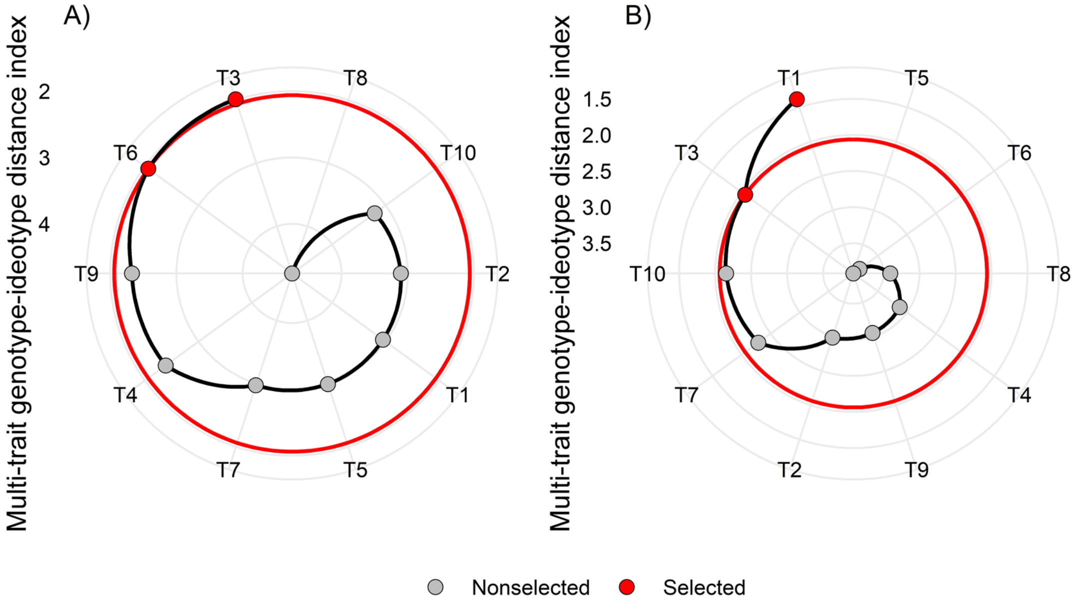

Figure 7: Treatments ranking in ascending order for the MGIDI index. The selected treatments are shown in red color and the red circle represents the cutpoint according to the selection pressure. T1: Airetama biquinho and Blue LEDs, T3: Airetama biquinho and fluorescent light and T6: BRS Moema and Blue LEDs.

Chlorophylls are photosynthetic pigments that absorb light to provide photosynthetic energy to plants (Fang *et al.*, 2022) and contribute to plant vigor due to photosynthetic efficiency (Huang *et al.*, 2013), mainly comprise chlorophyll a (Chl a), chlorophyll b (Chl b) and carotenoids (Car). Chlorophyll (Chl) absorb energy from sunlight and convert the light into chemical energy (Björn, 2015), while carotenoids have the function of collecting light in the range of 450-570 nm and protecting plants against photooxidative damage (Frank & Cogdell, 1996). For photosynthetic pigments, the cultivars showed different responses, while the contents of Chl*a*, Chl*b* and carotenoids in the cultivar BRS Moema were higher results for the blue, red LEDs and their combination. Shin *et al.* (2008), also observed that pigment biosynthesis was increased in *Doritaenopsis* plants grown with the plus of red and blue LEDs. These same authors report that the use of this mixed red and blue radiation can benefit the quality production of plants. The cultivar Airetama showed higher values of Chl*a* and Chl*b* for the fluorescent light, in contrast on lettuce (Chen *et al.,* 2014) and *Doritaenopsis* (Shin *et al.,* 2008) both under fluorescent lamps. It is therefore difficult to indicate a single spectrum of light suitable for the propagation of all plant species (Miler *et al.,* 2019), and in the present work, this response was species-specific in many of the analyzed variables.

There was a change in the behavior of BRS Moema plants at 76 DAE, when they were compared to 152 DAE for the variables SFM, RFM e SDM. At 76 DAE, these plants showed superiority when grown under blue LEDs, however, at 152 DAE, this result changed, with those grown under fluorescent and white LEDs with greater increment; suggesting that plant growth responses to light quality may not only be associated with species or cultivars, but also the plant growth stages (Chen *et al.,* 2014).

The use of artificial lighting has a positive effect on the growth and development of the biquinho pepper cultivars, proven by the gain of differential biomass between them. The greatest gains of SFM and SDM for BRS Moema cultivar were under fluorescent and white LEDs, for the variables RFM and RDM the greatest gains were observed in the fluorescent. The cultivar Airetama showed no differences ($p > 0.05$) for mass gain in different light sources. The increase gains attributed to the fluorescent and white LEDs in the period; may be related to the phase in which the plant is at the moment (Chen *et al.,* 2014). In contrast, Ajdanian *et al.* (2019), observed superiority with the application of blue and red light, as there was an increase in fresh and dry masses of cress (*Lepidium sativum*), as well as their biomass compared to plants grown under natural sunlight conditions.

Due to the large number of treatments tested (2 cultivars and 5 light sources = 10 treatments) it can be difficult to select the treatments that present the greatest selection differential, that is, desired characteristics. Using MGIDI we have the possibility to find the best treatments in a simple way and based on a multitrait framework (Olivoto & Nardino, 2020).

Light is an important signal element that regulates plant morphology, physiology and development during the plant growth cycle (Chen *et al.,* 2014), and the application of different light sources and their effects on plants is positive, as they result in the improvement of the biochemical characteristics and stimulates the use of these light sources in an effort to increase the quality of the plant and understand biochemically what happens with this application, and how it influences plant morphology. And this is only possible due to advances in technology, in which they must be constantly updated, and simultaneously stimulates the use of these in new studies and applications by researchers worldwide, and can also be used as allies in future plant production.

CONCLUSIONS

The results of the present study indicate that the light sources emitted in part of the growth of the plants becomes crucial during greenhouse conditions when these plants were transferred to soil. The treatments selected under greenhouse conditions are T3 (Airetama biquinho and fluorescent light) and T6 (BRS Moema and Blue LEDs) and in field conditions T1(Airetama biquinho and Blue LEDs) and T3 (Airetama biquinho and fluorescent light). Our discovery achieved the proposed objective, demonstrating that the use of LEDs is effective in the development and more vigorous growth of *Capsicum chinense*, and that this response is dependent cultivar.

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CONFLICT OF INTERESTS

There is no conflict of interests in carrying this research and publishing this manuscript.

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