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Research Article

Growth and flowering of carnation cultivated in different pot colors and protected environments

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Abstract

The *Dianthus caryophyllus* L. occupies the second position of the best sold cut flowers after rose. The choice of the environment and the cultivation container is crucial for flower production because, besides permitting higher temperature, light, and relative humidity management, it also impacts yield. This study evaluated the cultivation of yellow carnation in different protected environments and pot colours. The experiment was conducted in a factorial 2 × 4 (greenhouse and nursery x blue, red, brown, and black pots; the black pot was considered the control treatment). The photosynthetically active radiation, substrate temperature, and meteorological variables in the environments were monitored during the experiment's conduction as well the growth and productivity variables. The greenhouse significantly reduced solar radiation, generating favourable conditions for the initial growth of carnation plants. The nursery maintained higher levels of solar radiation, stimulating its flowering. The cultivation in brown pots provided higher quality plants regarding both vegetative growth and flowering. Therefore, brown pots are an option to substitute the black pots traditionally used for flower production. The use of the blue pot negatively influenced the development of carnation plants.

Keywords: *Dianthus caryophyllus*; light spectre; luminosity; ornamental species; protected environment

Introduction

In the flower and ornamental plants production chain, *Dianthus caryophyllus* L. occupies the second position of the best sold cut flowers after rose (Madhuri and Barad, 2018). This species is among the most sought flowers due to its beauty, cut length, and ability to flower during the full year (Castilla Valdés *et al.*, 2014).

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The consumption and production of flower and ornamental plant grew in Brazil (Paiva *et al*., 2020). In this scenario, the Midwest region of Brazil has excellent expansion potential in the flower industry, as it is an essential consumer of cut flowers (Oliveira *et al*., 2021). However, a significant part of the internal demand of the region is supplied by other Brazilian regions. Due to regional climatic conditions, this type of cultivation is viable with the use of protected environments (Hatamian and Salehi, 2017). Protected cultivation is more advantageous than cultivation in field conditions for some crops because it permits the production in different seasons and higher phytosanitary control. The structure of the protected environment protects the crop from rains, intense winds, direct radiation incidence, and stresses caused by animals (Paula *et al*., 2017; Salles *et al*., 2019; Costa *et al*., 2020a; Silva *et al*., 2021). Thus, it provides better sunlight use by plants.

Light is essential for plant growth. Besides providing energy for photosynthesis, it also acts in the signals that regulate the development through light receptors sensitive to different intensities, spectral qualities, and polarization states (Rego and Possamai, 2006). However, for these physiological processes to occur accordingly, the available luminous intensity must be inside the adequate spectral range for plants to absorb the radiation, permitting higher photosynthetic efficiency during their growth (Taiz *et al*., 2017).

The ideal range in which the main physiological events related to vegetal growth and development occur is between 400 and 700 nm wavelength, called the photosynthetically active radiation (PAR) (Dole and Wilkins, 2019). The efficiency in the conversion of this type of radiation intercepted in photoassimilates produces, among other beneficial functions, phytomass, varying according to the conditions in which the plant is cultivated (Caron *et al*., 2012).

In protected cultivation, the solar energy distribution is divided into three fractions: one part is reflected, another is absorbed, and the third is transmitted (Rebouças *et al*., 2015). Such light diffusion is influenced by structural factors of the environment, such as the type of material, used for cultivation and internal factors such as the reflectance of solar radiation by the vessels and supports inside (Von Zabeltitz, 2010; Costa *et al*., 2021a).

There are few studies addressing the color of pots in the growth and production of ornamental plants. In studies about the effect of the ambient and pot colors on ornamental pepper (*Capsicum frutescens*) Piramide cultivar, it was verified that a greenhouse covered with a low-density polyethylene film and a 42-50% shade cloth below the film promoted better initial growth to pepper plants and earlier fructification than the greenhouse with an 18-22% shade cloth. The brown pot in a greenhouse with a 42-50% shade cloth and the red pot in the greenhouse with an 18-22% shade cloth under the film positively influenced the growth and yield characteristics of pepper plants compared with the black pot (Costa *et al*., 2020b).

Based on the large-scale use of pots in the production and commercialization of flowers and the importance of using and expanding cultivation techniques suitable for these species, this study aims to evaluate the effect of solar radiation on the production of carnations in environments with different shading percentages and grown in pots of different colors.

Materials and Methods

The experiments were conducted in two protected environments (Latitude: 19° 05' 30,50"; Longitude: 51° 05' 55,64"; altitude: 510 m). According to the Köppen-Geiger classification, the region presents a tropical climate with rainy summers and dry winters (AW) (Peel *et al*., 2007).

As there were no repetitions of the protected environments, each was considered an experiment. The completely randomized design was used with five repetitions and five plants per plot in each environment. Initially, the data were submitted to individual analyses of variances regarding pot colors. Then, the mean square evaluation of the residues was conducted and, when possible, the joint analysis of the experiments (Banzatto and Kronka, 2013) in a factorial 2 × 4 (greenhouse and nursery X blue, red, brown, and black pots; the last type was considered the control treatment).

The protected environments used were: environment 1 – (E1) greenhouse, arched model, with galvanized iron structure 18.0 m x 8.0 m x 4.0 m (144 m^2), covered with 150-micron low-density polyethylene film (LDPF), air diffuser light, anti-drip, overhead opening sealed with 30% white screen, with side and front monofilament screen with 30% shading. LuxiNet 42/50% aluminized thermo-reflective screen, movable, under LDPF film; environment 2 – (E2) nursery of galvanized iron structure with 18.00 m length by 8.00 m width, 3.50 m height (144 m^2), closure in 45º inclination, with a black screen monofilament screen throughout its extension with 30% shading (Sombrite ®).

Both cultivation environments had metallic stands (0.80 m height) and an irrigation system with suspended micro-sprinklers of 70 liters per hour. Inside each environment were tested plastic pots of 0.8 L painted in brown, red, blue, and black.

The *D. caryophyllus* L. seeds used were of the cultivar 'Chabaud' (Figure 1) Selection 304 FELTRIN (93% germination). On March 31, 2019, the seeding was conducted in polypropylene trays with 128 cells of 34.4 cm width, 66.3 cm length, 6.2 cm height, and 0.0144 cm^3 volume. Three seeds were put in each cell, and both the trays and the pots were entirely filled with the peat-based substrate Carolina Soil® (Table 1).

Figure 1. Photos of different stages of the experiment where A: sowing of *D. caryophyllus* L. of the 'Chabaud' cultivar, B: emergence of seedlings, C: containers separated by color and D: data collection, in this case, flowers to measure their diameter

Table 1. Analysis of the chemical and physical characteristics of the substrate Carolina Soil®

N*	P_2O_5	K_2O	Ca	Mg	S	U-65 °C	OM	C	C/N
----------%----------									-
1.4	0.4	1.1	0.9	4.2	0.3	45.0	2.5	2.7	18.8
Cu	Zn	Fe	Mn	B	WRC	DD	pH	CEC	EC
----------%----------						$g\ m^{-3}$	$CaCl_2$	$mmol\ kg^{-1}$	$mS\ cm^{-1}$
0.006	0.036	1.752	0.240	0.008	51	130	6.2	850.0	0.87

*H65 °C = % of humidity at 65 °C; OM = organic matter; C/N = carbon/nitrogen ratio; WRC = water retention capacity; DD = Dry density; pH = hydrogen ion concentration; CEC = cation exchange capacity; EC = Electrical conductivity.

The emergence, pruning and transplant of seedlings to polyethylene pots occurred at 5, 15, and 28 days after sowing (DAS) respectively. The pots had a capacity of 800 mL, 9.7 cm height, 13 cm mouth diameter and 9.3 cm foot diameter.

During the experiments, meteorological variables were monitored and collected in the cultivation environments by measuring the incident photosynthetically active radiation (μmol m^{-2} s^{-1}) with a pyranometer Apogee® (model MP 200). This procedure was made three times a week, at 9:30 a.m. on days of an open sky (no clouds), and the device was put over the pots to intercept the radiation inside and outside the environment.

The substrate temperature was measured with a digital thermometer (°C) inserted in the pots twice a week at 1:00 p.m. The mean temperature variables, relative air humidity, and global solar radiation were monitored with an automatic station Irriplus® model E4000, located inside and at the center of each environment, registering a reading every 30 minutes.

The growth variables evaluated were: 1) plant height (PH), obtained by measuring the distance between the root crown and apex of seedlings with a millimeter tape measure; 2) crown diameter (CD), measuring five centimeters above the seedling crown with a digital caliper; and 3) the number of leaves (NL), obtained by counting the total number of leaves in the plant stem, measured 28, 68, and 89 days after transplanting (DAT). The yield variables were: 1) phenological stage of flower bud, characterized when 50% plus one plant obtained the first bud; 2) phenological stage of flowering, characterized when 50% plus one plant obtained the first open flower; 3) flower diameter (DFLOR), measured by the horizontal distance between the petal borders in opposite sides with a millimetric scale; 4) the number of open flowers (NOF), counting the total number of open flowers per plant.

At 89 days after the transplant (DAT), the root and the shoot of the plants were dried in a forced-air ventilation greenhouse at 65 °C per 72 hours and then weighed with an analytical balance to obtain the shoot dry matter (SDM) (g), and root dry matter (RDM) (g). The total dry matter (TDM) (g) was obtained by the sum of the shoot and root system dry matter.

The data were submitted to the analysis of variance (F-test), and the means were compared by Tukey's test (P-value < 0.05). To compare the cultivation environments, the joint analysis of the experiments was conducted since the division of mean square residues of the highest by the lowest did not exceed the 7:1, the ratio recommended by Banzatto and Kronka (2013), composing a double factorial 2 × 4 (two environments x fours pot colors).

To statistically compare the ambient data (micrometeorological variables), each collection month was considered a block from May to July (one repetition). Temperature (T°C), relative air humidity (UR%), global solar radiation (RG), and incident photosynthetically active radiation (RFA) were evaluated in a randomized block design with three repetitions. The reflected photosynthetically active radiation (RPAR) and the substrate temperature (Tsubs) were assessed in randomized blocks arranged in a factorial scheme 2 × 4 (two environments X four pot colors) with three repetitions. The results collected were submitted to the analysis of variance. The means from the two cultivation environments were compared using the F-test. The means from the pot colors were compared by the Tukey test, also at a 5% probability.

Results

By the results of the cultivation environments, we verified that air temperature and relative air humidity were similar during the experimental period, both in the protected and the external environments (Figure 2).

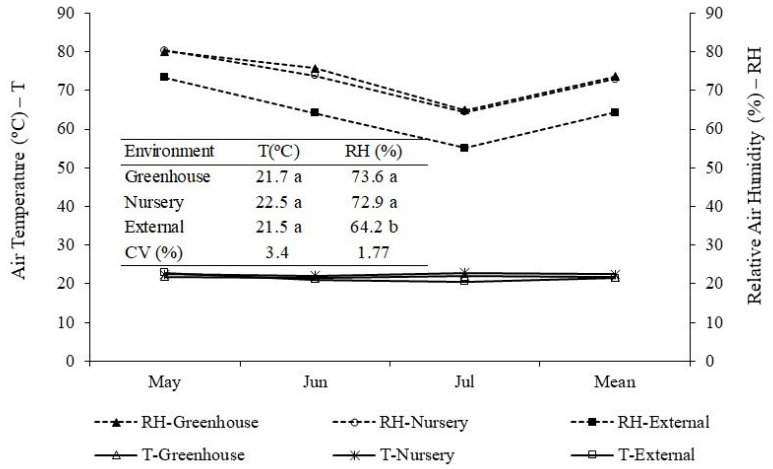

Figure 2. Air temperature (T, °C) and relative air humidity (RU, %) of the internal and external environments during carnation plants (*D. caryophyllus* L.) cultivation
Means followed by the same lowercase letter in the column do not differ statistically by the Tukey test at 5% probability. CV = coefficient of variation.

The average temperatures in the period presented no difference between the protected and the external environments. However, the relative humidity means in the protected environments (greenhouse and nursery) were higher than those verified in the external environment because, inside the protected environment, a micro-sprinkler irrigation system (Figure 2) was used, which provided higher relative humidity. The daily temperature of the environments (Figure 2) remained between 25.6 and 28.5 °C and, in E2, was on average 1.8 °C higher. The night temperature had higher variations of, on average, 0.6 °C in E2.

For the global solar radiation values (Figure 3), there was variation between 123.6 and 129.7 W m-² in E1 and between 226.9 and 241.2 W m-² in E2, where higher radiation incidence occurred, about 82% higher than in E1.

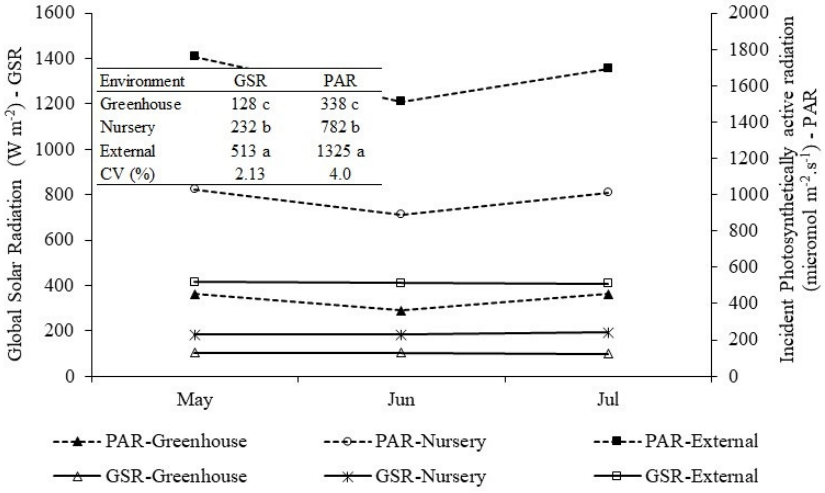

Figure 3. Global solar radiation (GSR, Wm^{-2}) and photosynthetically active radiation (PAR, micromol.$m^{-2}.s^{-1}$) in the internal and external environments during carnation plants (*D. caryophyllus* L.) cultivation
Means followed by the same lowercase letter in the column do not differ statistically by the Tukey test at 5 % probability. CV = coefficient of variation

Both the global solar radiation (GSR) and the photosynthetically active radiation (PAR) were different in the internal and external cultivation environments during the experimental period. The means of GSR and PAR were higher in the nursery than in the greenhouse, and both were lower than in the external (Figure 3). The environment with higher global solar radiation (E2) (Figure 3) favored higher average temperatures of the substrate (Figure 4), with a minimum temperature of 28.3 °C and a maximum of 33.2 °C.

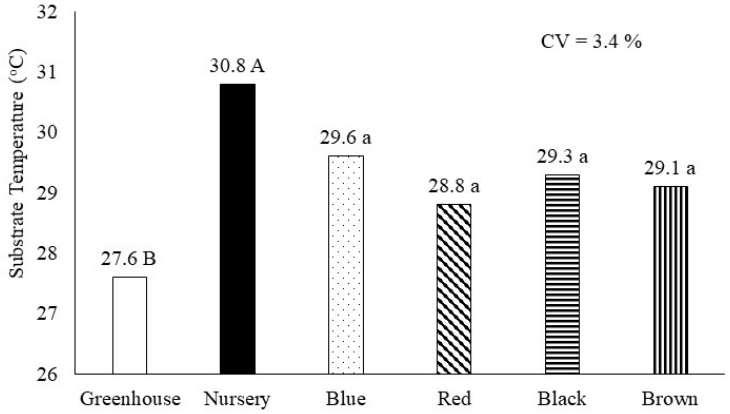

Figure 4. Substrate temperature (Tsub) in cultivation environments in pot colors during carnation (*D. caryophyllus* L.) cultivation

Equal lowercase letters for the pot colors (Tukey test) and equal uppercase letters for the protected environments (F-test) did not differ at a 5% probability. CV = coefficient of variation

Among the colors of the pots, it was observed that there was no difference in substrate temperature. The colors of the blue (29.6 °C) and black (29.3 °C) pots showed the highest average substrate temperature (Figure 4). The colors with the lowest reflected photosynthetically active radiation values (Figure 5) also had the highest substrate temperature (Figure 4).

Concerning the reflected photosynthetically active radiation, the environment with the highest shading level (greenhouse) resulted in the lowest incident radiation (Figure 2) and reflected (Figure 5). There was no significant variation in reflected radiation between vessel colors (Figure 5).

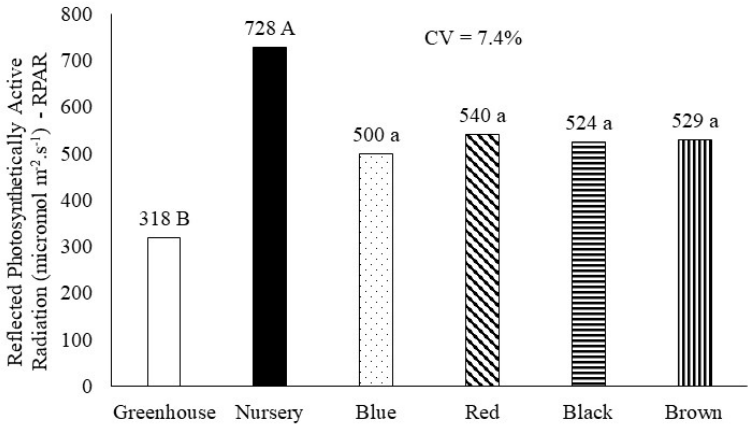

Figure 5. Reflected photosynthetically active radiation (RPAR, micromol.$m^{-2}.s^{-1}$) in the cultivation environments in the colors of the pots during carnation plants (*D. caryophyllus* L.) cultivation

Equal lowercase letters for the pot colors (Tukey test) and equal uppercase letters for the cultivation environments (F-test) did not differ at a 5% probability. CV = coefficient of variation.

An earlier beginning of the flower bud stage was observed in the plants from the environment with the highest shading level (E1) with an average difference of 11 days from E2 plants. Only the brown pots presented similar results to the control treatment (black pots), generating an antagonistic effect between the environments, which in E1 resulted in shorter periods, and more extended periods in E2 (Table 2).

Table 2. Beginning of the phenological stages of the flower bud and the flower opening of carnation plants (*D. caryophyllus* L.) in different pot colors and cultivation environments

Pot color	Flower bud (DAT)				Flower opening (DAT)			
	E1	IN/DE	E2	IN/DE	E1	IN/DE	E2	IN/DE
Blue	60 aA[1]	+13.2	61 aA	-14.1	85 aA	1	85 aA	-13.3
Red	63 aA	+18.9	64 aA	-9.9	86 aA	+1.2	89 aA	-9.2
Black	53 aA	1	71 abB	1	85 aA	1	98 abB[2]	1
Brown	56 aA	+5.7	80 bB	+12.7	88 aA	+3.5	111 bB[3]	+13.3
CV (%)	7.22		7.54		6.25		6.44	

[1]Equal lowercase letters do not differ between the pot colors (Tukey test), and equal uppercase letters do not differ between the cultivation environments (F-test) at 5% probability. CV = coefficient of variation. IN/DE = percentage increase or decrease of values regarding the control treatment (black pot). DAT = days after transplant. E1 =greenhouse; E2 = black screen. 2 and 3 estimated values (32% and 20% of the plants presented the 1st open flower on the last day of the project, at 89 DAT, respectively).

About the environments, the increase in the flower diameter was observed in the plants produced in E2. Complementarily, the influence of the pot colors in the increase of flower diameter is observed, which caused a rise higher than 13% in the plants from brown pots than in the plants from black pots (control) (Table 3).

Table 3. Crown diameter (CD), number of open flowers (NOF), and flower diameter (DFLOR) of carnation plants (*D. caryophyllus* L.) in different pot colors and protected cultivation environments

Environment	CD	IN/DE	NOF	IN/DE	DFLOR	IN/DE
E1	3.79 b[1]	-0.3	1.54 a	+18.5	3.42 b	-5.0
E2	4.07 a	+7.1	1.18 b	-9.2	3.80 a	+5.6
Pot color	CD	IN/DE	NOF	IN/DE	DFLOR	IN/DE
Blue	3.93 ab	+3.4	1.45 a	+11.5	3.30 b	-8.3
Red	4.07 a	+7.1	1.48 a	+13.8	3.47 b	-3.6
Black	3.80 b	1	1.30 a	1	3.60 b	1
Brown	3.92 ab	+3.2	1.22 a	-6.2	4.08 a	+13.3
CV (%)	5.60		23.18		9.43	

[1]Equal letters in the columns do not differ by the F-test for the environments and the Tukey test for pot colors, both at 5% probability. CV = coefficient of variation. IN/DE = percentage increase or decrease of values regarding the control treatment (black pot). E1 = greenhouse; E2 = black screen.

Environment 1 was better for the vegetative growth in the biometric variables measured, consequently providing higher shoot and root phytomass. Among the pot colors, the brown color presented significant increases for PH (7.4%) and NL (10.6%) in E1 and RDM (7.8%) in E2. Besides offering the higher increases in NL and dry matter, the blue color did not differ in the growth variables of carnation in E2 (Table 4).

Table 4. Interaction between environments and pot colors for the plant height (PH), number of leaves (NL), shoot dry matter (ADM), and root dry matter (RDM) by the evaluation of the experimental groups of carnation plants (*D. caryophyllus* L.)

Pot color	PH				NL			
	E1	IN/DE	E2	IN/DE	E1	IN/DE	E2	IN/DE
Blue	54.56 Ab[1]	-7.5	48.81 Ba	-0.4	77.04 Ac	-21.1	68.08 Aa	+5.8
Red	60.71 Aab	+2.9	46.13 Ba	-5.9	90.52 Ab	-7.3	64.32 Ba	1
Black	59.00 Aab	1	49.00 Ba	1	97.60 Aab	1	64.32 Ba	1
Brown	63.34 Aa	+7.4	46.33 Ba	-5.4	107.96 Aa	+10.6	60.06 Ba	-6.6
Pot color	**SDM**				**RDM**			
	E1	IN/DE	E2	IN/DE	E1	IN/DE	E2	IN/DE
Blue	3.68 Ab	-35.1	4.29 Aa	+10.0	1.60 Ab	-69.6	1.75 Aa	+14.4
Red	5.08 Aa	-10.4	4.06 Ba	+4.1	1.98 Aab	-13.9	1.49 Ba	-2.6
Black	5.67 Aa	1	3.90 Ba	1	2.30 Aa	1	1.53 Ba	1
Brown	5.25 Aa	-8.4	3.30 Ba	-15.4	2.01 Aab	-12.6	1.65 Aa	+7.8

[1]Equal uppercase letters in the same line and equal lowercase letters in the column do not differ by the F-test for the environments and the Tukey test for the pot colors, at 5% probability. IN/DE = percentage increase or decrease compared with the control (Black). E1 =greenhouse; E2 = black screen

Discussion

The factor solar radiation (global and photosynthetically active) was the one that most influenced the cultivation environment and plant growth differentiation in the protected environments. Besides the elevated thermal regime of the region, the cultivation environments had different behaviors during carnation's phenological stages. The average values of the day and night temperatures were 25.9 and 20.7 °C in E1, which favored carnation vegetative growth, and 27.7 and 21.3 °C in E2, which provided better flowering conditions.

The light use can influence the higher carnation growth in the greenhouse, temperature, and relative humidity conditions experienced by plants, which increase photosynthesis and, consequently, photoassimilate production (Taiz *et al*., 2017). Our study found the same results in environment E1, which can be attributed to the lower incident radiation (82% lower than E2). Bunt (1978) reported that the necessary environmental condition to produce high-quality carnation flowers was the high solar radiation available in the environment. The high light intensity increases stem diameter, flower size, and the number of carnation petals (Dahab, 1967). This fact is evidenced in the E2 environment, as high solar radiation stimulated flower production with an increase in the number of open flowers and floral diameter of carnations, but with a lower plant height.

It is worth mentioning that the cultivation of carnations in colored pots in an environment with lower incident radiation (E1) influenced vegetative growth in the biometric variables measured. However, if the producer's focus is flower production, his choice should be an environment with higher incident radiation (E2).

In our study, 12-week plants had an average of 1.36 flowers. Nevertheless, Baracaldo et al. (2019), at Mosquera, Colombia, verified flower buds (mean value of 1.88) only in the 21st week after sowing, indicating an earlier flowering in our study (Table 2). This effect can be explained by the differences in temperature and humidity between both places. In Mosquera, the average temperature and humidity within the greenhouse were 17.5° C and 76%, i.e., a lower temperature and a higher RU than in our study, 22.1 °C and 73.3 (Figure 1). Baracaldo *et al*. (2019) report that the plants had a more extended vegetative period than in our study. This fact explains the difference in the crown diameter, where the authors found a mean of 5.9 mm, while in our study, the mean was 3.9 mm.

Pagliarini *et al*. (2017) observed that the red net ChromatiNet® did not stimulate stem elongation, flowering, and stomatal conductance alterations as presented in other studies to the light quality that the species

needed in the phase evaluated. The red pot significantly influenced the crown diameter and presented increases in the carnation height, evidencing that each species responds differently to sunlight conditions imposed according to their necessities.

There were lower values for the variables regarding carnation growth in blue pots, being the color that caused the lower reflectance of the photosynthetically active radiation by plants, although the values were not significantly different from the other vessels. Many authors report the negative effect of blue materials, such as Kim *et al*. (2004) that found a reduction in the net photosynthetic rate of the blue color, causing a lower leaf production. Shahak *et al*. (2002) showed that the blue shade cloth Sombrite® generated shorter petioles, lower yield, and smaller plants. The color that stood out regarding carnation was brown. It presented higher reflectance in E1 and a lower substrate temperature, providing higher crop development conditions. Uemoto *et al*. (2010) verified that brown pellicles showed a high reflectance value and better thermal conditions on their surface, enhancing their surface thermal performance.

Conclusions

The greenhouse with 42-50% shading under low-density polyethylene film (LDPF) provided less solar radiation, favoring the growth of blackheads. However, the nursery with a black screen of 30% shading stimulated its flowering. The use of the blue pot negatively influenced the development of carnation plants. Carnation cultivation in brown pots provided higher quality plants regarding vegetative growth and flowering. Therefore, brown pots are an option to substitute the black pots traditionally used for flower production.

Authors' Contributions

SSAN and PLN contributed to setting up the experiment, collecting data, and writing the manuscript. AGS contributed to creating the figures and writing the manuscript. EC contributed to statistical analysis, creating the figures, and writing the manuscript. FFSB, GHCV and TD contributed to writing the manuscript. EPV contributed to statistical analysis, and writing the manuscript. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

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

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