Production and quality of ornamental peppers cultivated under colored shade nets

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Abstract
The cultivation of ornamental peppers in places with high temperature and incidence of solar radiation limits the production and quality of plants and fruits. The colored shade nets were introduced and adopted, because they reduce the temperature and intensity of solar radiation, as well as, low cost and simple to handle. The aimed was to evaluate the production and quality of C. chinense and C. frutescens cultivated under colored shade nets. The experiment was developed in the Floriculture Sector of the Agronomy Department of the Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil from February to August 2021 in entirely randomized design. C. chinense and C. frutescens were cultivated under red, pearl and aluminet nets with 35% shading and without net. At 150 days, production variables were quantified. The red net reduced the maximum temperature by at 4.1°C and the pearl and aluminet nets reduced the minimum temperature by 3°C. The maximum and minimum relative humidity was increased by 2.6 and 8.5%, respectively, by the red net. The pearl net obtained the lowest percentage of solar radiation incidence. Plant height was greater in the red and pearl nets, and C. frutescens. The diameter and stem fresh matter did not differ statistically between treatments. Root length was greater in the red and aluminet nets. The longitudinal and transverse canopy ratio was higher in C. chinense cultivated under the aluminet net. The number of leaves and leaves fresh matter was higher in pearl and aluminet net, and in C. frutescens, but leaves dry matter was higher in C. chinense. The number of flower buds and flowers, and flower buds dry matter was higher in C. chinense. The root fresh matter and dry matter was greater in C. chinense. The use of colored shade nets during the cultivation period effectively reduced temperature and light intensity. The aluminet net in association with C. chinense are recommended considering the compactness of height, pot coverage, greater number, shape and arrangement of fruits.

Keywords: Capsicum spp., floriculture, potential ornamental, shading

Introduction
The Capsicum genus consists of vegetables are widely produced and consumed (Olatunji & Afolayan, 2019), due to they have multiple marketable aptitudes such as use in food (Antonious, 2017), pesticide (Valková et al., 2021), pharmaceutical (Olatunji & Afolayan, 2019), nanotechnology (Velsankar et al., 2021) and ornamental (Lee et al., 2016) industries.

In recent years, the growth of the ornamental sector has occurred due to consumers being attracted to various species of the Capsicum genus due to the following characteristics that confer ornamental quality such as compact architecture; number, shape and position of fruits; coloration, shape and density of leaves and fruits, ease of cultivation, durability of leaves and fruits and continuous fruit production (Neitzke et al., 2016).

Among the species cultivated as ornamental pepper, C. chinense and C. frutescens gain notoriety, due to C. chinense having height between 50 to 100 cm, oval leaves and slightly wrinkled surface, white flowers and arranged in up 3 per node and elongated fruits with 5 to 7 cm long with 2.5 to 3.0 cm in diameter and coloration between light green to orange (Sarwa et al., 2012). C. frutescens has a height of up to 1.2 m, smooth and simple leaves, while to yellowish flowers and small, pungent, erect and slightly pointed fruits (Jaiswal et al., 2021).

The cultivation of ornamental pepper plants in locations with high temperature and incidence of solar radiation limits the production and quality of plants and fruits (Lekala et al., 2019), because CO2 assimilation of most C3 species saturates at low irradiance (600-900 µmol m-2 s-1) and excess of solar radiation causes heat stress, stomata closure, and reduced net photosynthesis (Ilić & Fallik, 2017). In addition, temperatures above 35 ºC impair cell division, leaf expansion and the abortion of buds.
flowers and fruits; as well as, burns on leaves and fruits (Flashman et al., 2015), compromising their availability and commercialization in the market.

Among the available technologies in crop production, the colored shade nets have been introduced and adopted because they reduce the temperature and intensity of solar radiation, as well as the attacks of pests and strong winds. Furthermore, they are low cost and simple to handle (Angmo et al., 2022). These nets transmit modified light spectrum from the sunlight that touches their wires, which, is spread over their canopy increasing production, quality and post-harvest (Ilić & Fallik, 2017; Mohawesh et al., 2022; Zha et al., 2022) through positive morphological and physiological responses, as reported in peppers grown under pearl net (Ilić et al., 2017), tomato grown under pearl and red net (Ilić et al., 2015), fresh herbs grown under red and pearl net (Buthelezi et al., 2016), lettuce grown under pearl and black net (Ntsaone et al., 2015), marigold and violet in red and yellow net (Zhare et al., 2019).

Linked to this, the choice of shading percentage should be made carefully, because excessive shading compromises the growth and development of crops, as it does not allow them to maintain effective photosynthesis during cultivation and subsequently compromises the production and quality of the final product (Martinez-Luscher et al., 2017). In view of the above, the use of colored shade nets in ornamental peppers needs to be studied to identify materials that reduce temperature and incidence of solar radiation conferring production and quality throughout cultivation. The aimed was to evaluate the production and quality of C. chinense and C. frutescens cultivated under colored shade nets.

**Material and Methods**

**Experimental Design**

The experiment was conducted in a 2x4 factorial scheme (varieties x colored shade nets), resulting in 8 treatments distributed in an entirely randomized design with five repetitions.

**Localization and Experimental Conduct**

The experiment was developed in the Floriculture Sector of the Agronomy Department of the Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil from February to August 2021.

According to the Köppen climate classification, mapped in Brazil by (Alvares et al., 2013), the climate in the region varies between the Cwa and Cwb types. The climate types correspond to Cwa: tropical humid zone with dry winter and with hot summer; and Cwb: tropical humid zone with dry winter and with temperate summer.

Seedlings of C. chinense cv. Biquinho Iracema and C. frutescens cv. Etna were purchased from Isla Sementes® (São Paulo, Brazil). These were grown in rigid polypropylene trays filled with Tropstrato® commercial substrate in a greenhouse, and when the seedlings presented two to three pairs of true leaves, they were transplanted into number 16 pots filled with the same substrate to roofs covered with red, pearl, and aluminet nets with 35% shading, purchased from Ginegar (São Paulo, Brazil) and without net.

These wooden structures had of 0.50x 0.50 x 0.70 m (width x length x height) arranged in the open air 2.0 m apart in the rows and 3.0 m between rows so that there was no shading from one to the other. The ornamental peppers were fertilized with 2 g of NPK 10-10-10 fertilizer, once a week, irrigation until the substrate reached field capacity and weeds were removed as necessary.

**Environment data**

Maximum and minimum temperature and relative humidity were recorded every 1 min in each shed using an AKSO AK-174 datalogger with a thermometer and hygrometer. Temperature was expressed in °C and relative humidity in %. Wavelength and solar radiation intensity intercepted by the colored nets were quantified by optical absorption using a spectrometer model USB4000, Ocean Optics. The spectra were processed using SpectraSuite software. The wavelength was expressed in nanometers (nm) and the intensity in percentage (%).

**Production and quality variables**

The following variables were quantified at 150 days after sowing:

- **Plant height:** was measured from the lower base of the pot to the last fully expanded leaf with the aid of a tape measure and the results were expressed in centimeters (cm).
- **Stem diameter:** was determined with the aid of a pachymeter and the results were expressed millimeters (mm).
- **Root length:** the plants were removed from the pots and the substrate adhered to the roots was removed with the aid of weak jets of water. The roots were the dried and the measurements taken with the aid of a ruler, starting at the neck of the plant and the results were expressed in cm.
- **Longitudinal and transverse canopy ratio:** was the quotient between the longitudinal and transverse canopy diameters. The results were expressed in mm.
- **Number of leaves, flower buds, flowers and fruits:**
were obtained at the end of the experiment based on their respective counts.

Production: was obtained by weighing the total number of fruits on each plant and expressed in grams (g).

Fruits length and diameter: four sampled fruits from each batch for spectral collection and reference analyses were measured, with the length being determined in cm. The mean of three measurements performed with the aid of a calliper in the peduncle region, central and at the apex of the fruit, was determined, and the diameter was obtained in mm.

Stem, leaves, flower buds, flowers and root fresh matter: a cut close to the neck of the plant was made with the objective of separating the aerial part from the roots. The stem, leaves, flowers buds, flowers and were separated. The root system was carefully removed from the pot and crushed manually with the aid of weak water jates. Then they were weighed. The results were obtained from weighing on a semi-analytical balance (Mark S2) with precision of ± 0.005g and were expressed in g.

Stem, leaves, flowers, buds and root dry matter: were placed, separately, in 5kg Kraft paper bags, and placed in the oven at 70 ºC until they reached constant weight. The results were expressed in %. The dry matter percentage was determined for following expression:

\[
\%\text{DM} = \frac{\text{Total dry matter}}{\text{Total fresh matter}} \times 100
\]

Statistical Analysis

The data obtained were subjected to normality (Shapiro-Wilk) and homogeneity (Bartlett) test of variances, analysis of variance (ANOVA) and test of means (Tukey at 5%) were performed in programming language R in version 3.6.3 (R Core Team, 2021). The graphs were made in the software Sigma Plot.

Results and Discussions

The temperature was reduced with colored shade nets, the red net being the one that promoted the most significant reduction of the maximum temperature, at 4.1 ºC and the pearl and aluminet nets the ones that promoted the most significant reduction of the minimum temperature at 3 ºC. Concerning the control, the maximum and minimum relative humidity increased with red shade net by 2.6 and 8.5%, respectively. The wavelength was concentrated between blue and far red (500-710 nm), and the intensity of solar radiation had an amplitude of 30.5 to 80.2% between treatments (Figure 1).

The optimal temperature for developing C. chinense and C. frutescens is around 21 to 33 ºC (Lekala et al., 2019; Angmo et al., 2022). At temperatures higher than 35 ºC, there is a reduction in cell division, leaf expansion, number of fruits, flower tip rot, and fruit burn (Mditshwa et al., 2017; Ilić & Fallik, 2017). Shading nets such as colored ones reduce the temperature by 1 to 5 ºC, depending on shading level, coloring, and growing location (Angmo et al., 2022). In this study, the control showed plants with leaf burns due to the high monthly maximum temperature of 36.1 ºC. Although the temperature surpasses the optimal range of development of ornamental pepper (>33.1 ºC), the plants cultivated under the pearl and aluminet nets did not show burns on the leaves.

Colored shade nets can raise the relative humidity from 3.2 to 12.9% (Mditshwa et al., 2019). In this study, the interval between the colored shade nets was lower, ranging from 0.1 in control to 8.5% in red shade nets.
net. This variation occurs as a function of the interaction between temperature, relative humidity, and intensity of solar radiation (Zhou et al., 2018).

C3 plants, such as pepper plants, need low irradiance between 600-900 µmol m$^{-2}$s$^{-1}$ and this corresponds to 40% incidence of solar radiation throughout the day (Flaishman et al., 2015). Above that, as presented by the control, can cause photoinhibition, heat stress, and stomatal closure resulting in decreased photosynthesis and carbohydrate distribution, affecting plant growth and fruit formation (Flaishman et al., 2015; Ilić & Fallik, 2017). On the other hand, the red and pearl nets presented the ideal amount of 40.7 and 31.5% of incidence of solar radiation, respectively, for developing ornamental pepper, optimizing agronomic performance (Mditshwa et al., 2019).

The fraction of light passed through the holes of the colored shade nets has its quality unchanged, but the fraction of light reached by the wires is spectrally modified (Zare et al., 2019). The red net transmits in red and far-red, while the pearl transmits in blue, yellow, green, red, and infrared (Ilić & Fallik, 2017).

The plant height was greater in the red and pearl compared to aluminet, but did not differ statistically from the control. Also, C. frutescens obtained greater height compared to C. chinense (Figure 2A and B). Stem diameter did not differ statistically between treatments (x= 11.74 ± 1.55 mm). Root length was greater in red and aluminet nets compared to the other treatments (Figure 2C). The longitudinal and transverse canopy ratio was higher in C. chinense grown under aluminet net compared to the control (Figure 2D).

Plant height was greater in red and pearl shade nets compared to aluminet, due to the balance in the ratio of red light (R): far red (FR), due to the light reaching the wires of these nets being filtered and transmitted as red light in greater proportion to far red, reducing plant compaction (Silva et al., 2016; Ilić & Fallik, 2017). This occurs, because stem elongation is associated with phytochrome being active by red light and deactivated by far red (Díaz-Pérez & John, 2019; Johnson et al., 2020). Plant height was higher in C. frutescens, because, morphologically, this pepper has greater height than C. chinense (Olatunji & Afolayan, 2018). In contrast, the height obtained in this study is shorter than that reported by (Sarwa et al., 2012) and (Jaiswal et al., 2021), thus, these compact ornamental peppers are easily accepted by consumers due to the ease of growing them in pots, ease of displaying them in places with limited space, and durability compared to the medium and tall sizes intended for landscaping (Neitzke et al., 2016).

Generally, plants grown in full sun have their height reduced, due to the light temperatures and intensity of solar radiation causing damage to the photosynthetic organs causing the photoinhibition, closure of stomata, reduction of photosynthesis and distribution of carbohydrates for investment in growth (Silva et al., 2016; Ilić & Fallik, 2017). On the other hand, in the literature, there are reports of species in which the plant height in full sun and under colored shade nets did not differ as obtained in this study (Souza et al., 2014; Silva et al., 2016).

This occurs in species that are adapted to warm climate and cultivation in full sun as the pepper (Souza et al., 2014), however, these climatic conditions may affect the visual characteristics of the plant and the fruits causing them to burn as observed in this study in the control treatment that obtained a temperature of 36.2 °C and solar radiation intensity of 80.2%, and consequently, consumer repulsion (Souza et al., 2014). This repulsion is explained by the fact that the burns affect the surface texture, brightness and coloration of the leaves and fruits, which are characteristics observed in the purchase decision making of ornamental pepper plants (Neitzke et al., 2016).

Plants grown in full sun obtain a greater stem diameter in comparison with shaded plants, which have thin stems due to stretching (Silva et al., 2016). However, in this study, plants under all shade nets did not show such...
behavior because 35% shading did not compromise light interception as much as nets with shading higher than > 40% as observed in (Díaz-Pérez & John, 2019) and (Souza et al., 2014).

On the other hand, the greatest root length was observed in both ornamental peppers shaded by the red and aluminet nets. In red net, the ratio of red light (R): far red (FR) was higher, consequently, phytochrome B (PHYB) is activated and induces root formation via auxin signaling (Chen et al., 2016; Rosado et al., 2021). The aluminet net, on the other hand, has lower red light (R): far red (FR) ratio, i.e., there is no PHYB actuation in root formation and growth (Rosado et al., 2021). On the other hand, the canopy of C. frutescens had the highest number of leaves and C. chinense had the highest longitudinal and transverse canopy ratio, contributing to light uptake under the canopy, production of photoassimilates and investment in root growth (Ribeiro et al., 2018).

The longitudinal and transverse canopy ratio allows the evaluation of the equilibrium of the canopy of potted peppers in ornamental industry, which should have good coverage of the pot, swelling and firm stems with good support (Cruz et al., 2017). The longitudinal and transverse canopy ratio was higher in C. chinense cultivated on the aluminet shade net, because the oval leaves, although spaced apart, had greater pot coverage in the longitudinal direction compared to the other treatments (Sarwa et al., 2012). In addition, the aluminet net provided greater root length, ensuring effective support of the plant without tipping (Silva et al., 2016; Ribeiro et al., 2018).

The number of leaves was higher in the pearl and aluminet nets compared to the other treatments. Also, C. frutescens had more leaves compared to C. chinense (Figure 3A and B). The number of flower buds and flowers was higher in C. chinense compared to C. frutescens (Figure 3C and D).

The leaves fresh and stem matter was higher in C. frutescens compared to C. chinense (Figure 4A and D). Root fresh matter was higher in C. chinense compared to C. frutescens (Figure 4F). The stem fresh matter did not differ statistically among the treatments with the nets compared to the control (Figure 4C). Leaves, stem, bud, and root dry matter was greater in C. chinense compared to C. frutescens (Figure 4B, E, G and H).

The number of leaves was higher in the pearl and aluminet nets, because plants shaded by nets tend to produce more leaves as a phenotypic adaptation to the reduction of light intensity as an alternative to the improvement of the capture of incident light in the canopy (Mathuer et al., 2018). Otherwise, ATP production would be insufficient for carbon fixation and biosynthesis, due to low ATPase activity, and Rubisco, thus reducing growth, development, and fruit formation (Shao et al., 2014; Mathuer et al., 2018).

The number of leaves and leaves fresh matter was higher in C. frutescens, because, it has a dense canopy with a greater number of leaves (Mditshwa et al., 2019). The dense canopy along with the coloration and brightness of this ornamental pepper allows contrast with the red of the fruits, which is highly appreciated in the ornamental sphere by consumers (Neitzke et al., 2016). Leaves dry matter was higher in C. chinense because the leaf area of this pepper is larger than that of C. frutescens, and the greater longitudinal and transverse canopy ratio promoted greater uptake of solar radiation, which increased the production of photoassimilates, which were converted into greater dry matter (Gao et al., 2021).

C. chinense, morphologically, has flower buds and flowers covered by leaves and the shading caused by the nets reduced the temperature (<35°C) promoting less buds and flowers abortion via heat stress (Mditshwa et al., 2017 and 2019; Ilić & Fallik, 2017). As well as, higher flower buds dry matter, due to lower of incidence of bud abortion and reduction in temperature (Ilić & Fallik, 2017).

The fresh matter of flowers and buds did not differ statistically between treatments, but was greater in

![Figure 3. Number of leaves (A and B), flower buds (C) and flowers (D) of C. chinense and C. frutescens cultivated under colored shade nets. *Capital letters refer to colored shade nets, and lowercase letters refer ornamental peppers. Different capital and lowercase letters differ from each other by the Tukey test at 5%.](image)
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... treatment with pearl (x= 1.52 g) and aluminet (x=1.32 g) shade nets. The red shade net transmits the red and far-red spectrums, while the pearl net transmits in the blue, yellow, green, red and infrared spectrums and aluminet net absorbs in all spectra but does not transmit in any spectrum (Ilić & Fallik, 2017). In view of this, pearl and aluminet shade nets have lower ratio of the red light (R) to far red (FR) compared to red net (Mahmood et al., 2018; Zhou et al., 2018), thus, photoreversibility of phytochrome and flowering swimsuits occurred (Ilić & Fallik, 2017; Mditshwa et al., 2019), which led to higher fruit production. Despite C. chinense showed...
higher longitudinal and transverse canopy ratio, a more significant number of fruits occurred due to greater light penetration in the canopy allowing the direction of photoassimilates to the drains (Mditshwa et al., 2019). Ornamentally, consumers prefer pepper plants with a larger number of fruits, due to the contrast of these with the foliage, as well as for consumption or preparation of by-products, such as jams and jellies (Neitzke et al., 2016).

On the other hand, C. frutescens obtained higher fruit production, this may have occurred, due to the lower number of flowers of this pepper plant were not aborted, due to the temperature reduction obtained by the screens, these being reverted also in few fruits, which, obtained greater use in the photoassimilates distribution and consequently, higher weight gain (Mditshwa et al., 2017 and 2019; Ilić & Fallik, 2017).

Morphologically, the fruits of C. chinense have the shape of spherical berries, and the fruits of C. frutescens have an elongated shape, corroborating the result found (Nascimento et al., 2019). Spherical fruits like C. chinense are preferred by consumers for ornamentation of dishes and low pungency (Nascimento et al., 2019).

Conclusion
The use of colored shade nets during the cultivation period effectively reduced temperature and light intensity. The aluminet net in association with C. chinense are recommended considering the compactness of height, pot coverage, greater number, shape and arrangement of fruits.

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