Bell Pepper (Capsicum annum L.) under Colored Shade Nets: Plant Growth and Physiological Responses

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Abstract. Use of colored shade nets has shown benefits in bell pepper and other horticultural crops. There is still, however, limited information on plant growth and physiology of bell pepper crop grown under colored shade nets. The objective was to determine the effects of colored shade nets on plant growth, leaf gas exchange, and leaf pigments of field-grown bell pepper. Experimental design was a randomized complete block with four replications and five shade treatments (black, red, silver, and white nets, and an uncovered control). Mean and maximal air temperature and midday root zone temperature (RZT) were highest in the unshaded treatment. Differences in air temperatures between shade net treatments were smaller compared with the differences in RZT between treatments. Plant fresh weight and stem diameter were reduced in the unshaded treatment, and there were no plant fresh weight and stem diameter differences among shade nets. The incidence of Phytophthora blight (caused by Phytophthora capsici) was greatest in the unshaded treatment. Leaf stomatal conductance (gs), photosynthesis, and photosystem II efficiency were reduced and leaf temperature increased in unshaded conditions. Leaf net photosynthesis, gs, internal CO2, and PSII efficiency decreased with increasing leaf temperature. Differences in leaf temperature among shade net treatments were because of differences in solar radiation captured by leaves. Leaf total carotenoids were lowest in unshaded conditions and there were no differences in total carotenoids among the shade nets. Chlorophyll a concentration and chlorophyll a/b ratio was lowest in unshaded conditions. Leaf total phenols, flavonoids, and cupric reducing antioxidant capacity (CUPRAC) values were highest in red net and in unshaded conditions. Trolox equivalent antioxidant capacity (TEAC) values were highest in red net and lowest in silver net. In conclusion, compared with unshaded conditions, shade nets resulted in improved bell pepper plant growth and leaf gas exchange. These responses were due primarily to the reduced air, plant, and soil temperatures under shaded conditions, regardless of the color of shade net. The differences in plant growth and function due to color of shade net were inconsistent or minor for most of the plant variables measured.

Materials and Methods

This study was conducted at the Horticulture Farm, University of Georgia (lat. 31.4803° N, long. 83.5211° W), Tifton, GA during the spring seasons of 2015 and 2016. The soil was a Tifton Sandy Loam (a fine, loamy-skeletal, thermic Plinthic Kandiudults) with a pH of 6.5. Before laying mulch, a malch-laying machine (Kenco Manufacturer, Ruskin, FL), the soil was fertilized with N, P, and K at 50, 22.0, and 41.5 kg·ha⁻¹, respectively, using a 10–10–10 granular fertilizer (Rainbow Plant Food, Montgomery, AL). Fertilizer was incorporated into the soil. Plastic film mulch [black, low-density polyethylene with a slick surface texture, 1.52 m wide and 25 μm thick (Intergro, Clearwater, FL)] was laid. Drip irrigation tape (30 cm emitter spacing and a 12.6 mL·min⁻¹ emitter flow at 0.55 bar of pressure (Aqua traxx; Toro, Abilene, TX)] was placed 5 cm deep in the center of the bed.

Experimental design was a randomized complete block with four replications and five shade treatments (four colored nets and an unshaded control). Colored nets were black (47% shade), red (42% shade), silver (40% shade), and white (41% shade) (Fig. 1). These values of shade level are as reported by the manufacturer (Green-tek, Janesville, WI) and are within the optimal shade level (30% to 46% shade) for bell pepper (Diaz-Perez, 2014). Each shade net was placed on a wooden rectangular structure (15 m wide × 6 m long × 5 m high). Experimental design was a randomized complete block with four replications and 10 treatments [5 shade treatments (black, red, silver, and white nets and an unshaded control; Green-tek, Janesville, WI)]. Shade nets reduced solar radiation by about 40%.

Bell pepper (‘PS 09979325’) transplants were produced in a greenhouse using peat-based medium (All Purpose Mix, Pro-Mix; Quakertown, PA) and polystyrene 200-cell (2.5 x 2.5 cm cell) trays. Plants were established on individual raised beds (formed on 1.8-m centers; 0.76 m wide). The length of individual leaf area, and individual leaf weight increased, whereas number of leaves per plant and specific leaf weight declined (Diaz-Perez, 2013).

Although black nets are most commonly used, there has been increased interest in colored nets. Colored nets may influence plant growth, yield, and fruit quality because of their ability to modify both light quality and quantity (Arthurs et al., 2013; Fallik, 2009; Ilic et al., 2017). Regardless of net color, shade nets reduce solar radiation with concomitant reductions in air, plant, and soil temperatures. Use of colored shading nets has shown benefits in various horticultural crops, although there is limited information on bell pepper (Stamps, 2009). The objective of our work was to determine the effects of colored shade nets on plant growth, leaf gas exchange, and leaf pigments of field-grown bell pepper.

Received for publication 21 May 2019. Accepted for publication 27 June 2019.

Financial support was provided by the Georgia Agricultural Experiment Stations. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2014-33610-22604.

We thank Jesús Bautista, Gunawati Gunawan, and Nélida Bautista for their invaluable technical support and Jason Brock of the Plant Disease Clinic, University of Georgia, for identification of plant diseases. We appreciate the thorough review of the manuscript by Erick Smith, André Luiz Biscaia Ribeiro da Silva, and the anonymous reviewers.

Mention of trade names in this publication does not imply endorsement by the University of Georgia of products named, nor criticism of similar ones not mentioned.

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the field experimental plot was 6 m. Six-week-old transplants were planted on 12 Apr. 2015 and 20 Apr. 2016 in two rows (staggered) per bed, with a 30 cm separation between plants and 36 cm separation between rows (40 plants per plot). About 240 mL of starter fertilizer solution (555 ppm N; 821 ppm P; 0 ppm K) was applied directly to the base of each transplant. Starting three weeks after transplanting, plants were fertilized weekly through the drip system. Total major nutrients applied were 200 kg·ha⁻¹ [nitrogen (N)], 22 kg·ha⁻¹ [phosphorus (P)], and 191 kg·ha⁻¹ [potassium (K)]. The crop was grown following the recommendations of the University of Georgia Extension Service.

Plants were irrigated with an amount of water equivalent to 100% crop evapotranspiration (ETc), which was calculated by multiplying the reference evapotranspiration (ET0) by the crop factor (dependent on the crop stage of development). Water was applied when cumulative ETc was 1.2 mm, which corresponded to about every 2 to 3 d in mature plants (mean ET0 was 5 mm·d⁻¹).

**Microenvironment.** Air temperature and relative humidity were measured periodically during the season (both in 2015 and 2016) with dataloggers (HOBO, MX2301A; Instrumentation Laboratory). Air temperature and relative humidity were measured periodically (IR) thermometer on 18 and 25 May, and 3 June 2015 (three measurements per experimental plot). Root zone temperature (8 cm deep) at midday was measured manually with a digital thermometer the same days as canopy temperature. The ET0 and rainfall data were obtained from a nearby University of Georgia weather station (less than 300 m). Plant diseases was evaluated at the Plant Disease Clinic, University of Georgia, Tifton Campus. Presence of TSWV in symptomatic plants was confirmed by enzyme-linked immunosorbent assay (ELISA).

**Leaf gas exchange and Photosystem II efficiency.** Simultaneous measurements of leaf gas exchange (net photosynthesis, gs, internal CO₂ concentration and transpiration), leaf temperature, photosynthetically active radiation (PAR), and fluorescence determined as Photosystem II (PSII) efficiency were made with an IR gas analyzer (LI-COR 6400 IRGA with an integrated 6400-40 leaf chamber fluorometer; LI-COR, Inc., Lincoln, NE). PSII efficiency is the fraction of absorbed PSI photons used in photochemistry, and PSI is measured with a light-adapted leaf (LI-COR, 2003). Water use efficiency was calculated as the ratio between net photosynthesis and transpiration. Air flow rate was set at 300 μmol·m⁻²·s⁻¹ on the reference side. The CO₂ concentration was set at 400 μmol·mol⁻¹ with a CO₂ mixer and a CO₂ tank. Measurements were conducted in developed plants on clear days (unshaded conditions PAR > 1900 μmol·m⁻²·s⁻¹) at 1200 to 1500 HR using two developed and fully exposed leaves per plot.

**Leaf chemical composition.** Six leaves per treatment were collected on 29 May and 5 June 2015 and analyzed individually for chemical composition. Carotenoids and chlorophyll (Chl) a and b were determined in fresh leaves. Leaf tissue was ground in acetone (90% v/v), filtered, and taken to a volume of 50 mL (Lic et al., 2012; Lichtenthaler, 1987). Pigments concentrations were calculated from the absorbance of the extract at 470, 645, and 663 nm. Total phenols were determined as a measure of total antioxidant capacity following the Follin–Ciocalteau method (Singleton et al., 1999), and data were expressed as gallic acid equivalents. Antioxidant capacity was determined by CUPRAC and TEAC methods (Barro et al., 2007; Castro-Concha et al., 2014). Total flavonoid concentration was determined by the aluminum chloride colorimetric method and expressed in quercetin equivalents (Rawat et al., 2014).

**Results and Discussion**

**Microclimatological factors.** Seasonal averages of air temperature and relative humidity for 2015 and 2016 are shown in Tables 1 and 2. In 2015, minimal air temperatures were highest under the black net and lowest in unshaded conditions (Table 1). Mean air temperature was lowest under the black net.

**Table 1. Effect of colored shade nets on air and canopy temperature, root zone temperature (RZT), and relative humidity in bell pepper (Tifton, GA, Spring 2015).**

| Shade   | Air temp (°C) | Canopy temp (°C) | Relative humidity (%) |
|---------|---------------|-------------------|-----------------------|
|         | Minimal       | Mean              | Maximal               | Minimal       | Mean              | Maximal               |
| Black   | 22.32 a      | 27.0 c            | 33.1 b                | 27.1 b        | 34.0 b            | 49.5 a                |
| Red     | 22.28 ab     | 27.1 b            | 33.1 b                | 27.0 b        | 34.9 b            | 46.8 c                |
| Silver  | 22.26 b      | 27.1 b            | 33.0 c                | 27.2 b        | 34.9 b            | 48.3 b                |
| White   | nd            | nd                | nd                    | nd            | nd                | nd                    |
| Unshaded| 22.17 c      | 27.2 a            | 33.9 a                | 29.4 a        | 35.7 a            | 45.7 d                |

P < 0.0001

Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

Nd = not determined.
Table 2. Effect of colored shade nets on air temperature and relative humidity in bell pepper (Tifton, GA, Spring 2016).

| Shade         | Air temp (°C) |               | Relative humidity (%) |               |
|--------------|---------------|---------------|-----------------------|---------------|
|              | Minimal       | Mean          | Maximal               | Minimal       | Mean          | Maximal               |
| Black        | 20.52 b<sup>+</sup> | 26.2 c       | 31.8 c                | 43.2 a        | 62.5 a        | 82.7 a                |
| Red          | 20.49 c       | 26.3 b       | 32.1 b                | 39.7 c        | 58.4 c        | 79.0 b                |
| Silver       | 20.56 b       | 26.4 b       | 31.9 c                | 40.9 b        | 60.5 b        | 81.9 a                |
| Unshaded     | 20.66 b       | 26.6 a       | 32.6 a                | 41.3 b        | 56.0 d        | 71.5 c                |

<sup>P</sup><sup>+</sup>Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

Table 3. Effect of colored shade nets on plant growth, leaf chlorophyll index, air temperature, and incidence of soil-borne diseases in bell pepper (Tifton, GA, Spring 2015).

| Shade | Ht (cm) | Stem diam (mm) | Chlorophyll index | Incidence soil-borne diseases (%) |
|-------|--------|----------------|-------------------|-----------------------------------|
| Black | 39.8 a | 10.0 a        | 66.2 b            | 26 ab                             |
| Red   | 38.0 a | 9.8 a         | 68.4 ab           | 25 ab                             |
| Silver| 41.1 a | 10.1 a        | 69.0 a            | 29 ab                             |
| White | 38.0 a | 10.5 a        | 68.9 a            | 23 b                              |
| Unshaded | 18.6 b | 6.9 b     | 69.1 a            | 46 a                              |

<sup>P</sup>Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

Table 4. Effect of colored shade nets on bell pepper plant growth, leaf chlorophyll index, air temperature, and incidence of soil-borne diseases (Tifton, GA, Spring 2016).

| Shade      | Stem diam (mm) | Top fresh wt (g) | Chlorophyll index | Incidence soil-borne disease (%) |
|------------|----------------|------------------|-------------------|----------------------------------|
| Black      | 11.9 ab<sup>+</sup> | 373 ab        | 60.4 b            | Southern blight: 13.1  Phytophthora blight: 0.288 |
| Red        | 12.0 ab        | 393 ab         | 60.7 b            | 15.6  1.3 b                      |
| Silver     | 12.8 a         | 431 ab         | 60.7 b            | 14.7  0.3 b                      |
| White      | 12.0 ab        | 441 a          | 61.4 b            | 13.4  2.2 b                      |
| Unshaded   | 11.2 b         | 291 b          | 62.8 a            | 18.8  13.9 a                     |

<sup>P</sup>Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

and highest in unshaded conditions. Maximal air temperature was lowest under the silver net and highest under unshaded conditions. Midday RZTs were highest in the unshaded treatment, and there were no RZT differences between shading nets (Table 1). Root zone temperature increased with increasing PAR ($r^2 = 0.936$) under the shade net treatments, while air temperature was unrelated to PAR. Minimal, mean, and maximal relative humidity was among the lowest under the red net and in unshaded conditions. In 2016, minimal air temperatures were lowest under the red net and highest in unshaded conditions (Table 2). Mean air temperature was lowest under the black net and highest in unshaded conditions, while maximal air temperature was lowest under the black and silver nets and had highest values in the unshaded treatment. Minimal relative humidity was lowest under the red net and highest under the black net. Mean relative humidity was lowest in unshaded conditions and highest under the black net. Maximal relative humidity was lowest under unshaded conditions and highest under the black net.

Shade nets affect the quality and quantity of solar radiation received by the crop as well as the air and soil temperature under the net. In the present study, the differences in air temperatures between shade net treatments were smaller compared with the differences in RZT. In a study in Florida using shadehouse structures with full covering, daily maximum air temperatures were higher inside shadehouses with red, blue, and pearl nets compared with black nets or uncovered conditions (Arthurs et al., 2013). In the present study in which shade structures were rectangular prisms and the net covered only the upper portion of the structure, maximal air temperature was lowest under the silver net and highest under unshaded conditions. In a study in Hungary using colored shade nets over pepper, air temperature showed relatively little changes in response to colored shade nets, and air temperature decreased with increasing shade level (Ombòdi et al., 2015). The reduction of solar radiation (PAR, IR, and longwave radiation) under shade nets probably contributed to the reduced air temperatures and reduced RZTs under shaded conditions, compared with unshaded conditions. Reduced air and leaf temperature under shade nets resulted in diminished plant transpiration due to reduced evaporative demand, compared with the unshaded treatment.

**Plant growth and chlorophyll index.** In 2015, plant height and stem diameter were reduced in the unshaded treatment (Table 3), and there were no differences in plant height and stem diameter among shade nets. Chlorophyll index was reduced under the black net. In 2016, stem diameter and top fresh weight were reduced in unshaded conditions (Table 4). Chlorophyll index was the highest in unshaded conditions, while there were no differences in chlorophyll indexes among shade nets.

Light is essential for photosynthesis in plants, but it may also influence plant growth and development through the action of several photoreceptors such as phytochromes (Smith, 2000). Red nets have been found to reduce the red/far-red ratio resulting in enhanced vegetative growth in various crops (Oren-Shamir et al., 2001; Shahak, 2008). In this study, shade nets modified light quantity (i.e., PAR) received by bell pepper plants; the effect of shade net treatments on light quality was not measured. Black nets and colored nets have been reported to influence plant growth of bell pepper and other vegetables (Díaz-Pérez, 2013; Ilic et al., 2017; Ombòdi et al., 2015; Shahak, 2008). In greenhouse-grown eggplant, plant height, leaf number, total leaf area, individual leaf area, and plant fresh weight were increased under shading compared with an open field (Aied et al., 2017).

**Plant diseases.** In 2015, the incidence of soil-borne diseases (unidentified diseases) was increased in unshaded conditions (Table 3). In 2016, the incidence of southern blight was unaffected by shade treatments, while the incidence of Phytophthora blight was increased in unshaded conditions (Table 4). The incidence of Tomato spotted wilt incidence was small and similar among shade treatments (mean = 0.51%).
Table 5. Effect of colored shade nets on leaf net photosynthesis ($P_{\text{net}}$), stomatal conductance ($g_s$), internal CO$_2$ photosystem II (PSII) efficiency, photosynthetic water use efficiency ($WUE$), photosynthetically active radiation ($PAR$), and leaf temperature ($T_{\text{leaf}}$) in bell pepper (Tifton, GA, Spring 2015).

| Shade      | $P_{\text{net}}$ (µmol·m$^{-2}$·s$^{-1}$) | $g_s$ (mmol·m$^{-2}$·s$^{-1}$) | Internal CO$_2$ (µmol·mol$^{-1}$) | PSII efficiency* | $WUE$ (µmol·m$^{-2}$·s$^{-1}$) | $PAR$ (µmol·m$^{-2}$·s$^{-1}$) | $T_{\text{leaf}}$ (°C) |
|------------|-----------------------------------------|--------------------------------|-----------------------------------|------------------|-------------------------------|-------------------------------|-----------------|
| Black      | 28.4 ab                                 | 756 ab                         | 396.8 a                           | 0.260 a          | 1.68                          | 985 d                        | 31.8 b           |
| Red        | 28.0 ab                                 | 769 ab                         | 394.6 a                           | 0.231 a          | 1.67                          | 1064 c                       | 31.8 b           |
| Silver     | 29.1 a                                  | 820 a                          | 370.9 a                           | 0.242 a          | 1.66                          | 1102 bc                      | 31.9 b           |
| White      | 26.5 bc                                 | 613 bc                         | 290.9 ab                          | 0.234 a          | 1.75                          | 1135 b                       | 33.2 a           |
| Unshaded   | 25.1 c                                  | 515 c                          | 280.2 b                           | 0.161 b          | 1.74                          | 1851 a                       | 34.2 a           |
| $P$        | 0.0004                                  | <0.0001                        | 0.0011                            | <0.0001          | 0.057                         | <0.0001                     | 0.0001          |

*Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

*Photosystem II (PSII) efficiency. It is the fraction of absorbed PSII photons that are used in photochemistry and is used as an indicator of plant stress.

Table 6. Effect of colored shade nets on leaf net photosynthesis ($P_{\text{net}}$), stomatal conductance ($g_s$), internal CO$_2$, photosystem II (PSII) efficiency, photosynthetic water use efficiency ($WUE$), photosynthetically active radiation ($PAR$), and leaf temperature ($T_{\text{leaf}}$) in bell pepper (Tifton, GA, Spring 2016).

| Shade      | $P_{\text{net}}$ (µmol·m$^{-2}$·s$^{-1}$) | $g_s$ (mmol·m$^{-2}$·s$^{-1}$) | Internal CO$_2$ (µmol·mol$^{-1}$) | PSII efficiency* | $WUE$ (µmol·m$^{-2}$·s$^{-1}$) | $PAR$ (µmol·m$^{-2}$·s$^{-1}$) | $T_{\text{leaf}}$ (°C) |
|------------|-----------------------------------------|--------------------------------|-----------------------------------|------------------|-------------------------------|-------------------------------|-----------------|
| Black      | 25.7 a                                  | 539 ab                         | 293.7 ab                          | 0.23 ab          | 1.65 b                        | 1051 c                       | 32.48 bc         |
| Red        | 28.0 a                                  | 655 a                          | 301.9 a                           | 0.21 b           | 1.65 b                        | 1204 b                       | 31.60 c          |
| Silver     | 26.9 a                                  | 544 ab                         | 287.5 ab                          | 0.23 ab          | 1.78 ab                        | 1200 b                       | 32.31 bc         |
| White      | 23.9 a                                  | 421 b                          | 277.1 bc                          | 0.25 a           | 1.81 ab                        | 1066 c                       | 33.06 ab         |
| Unshaded   | 24.7 a                                  | 417 b                          | 266.6 c                           | 0.15 c           | 1.87 a                        | 1991 a                       | 33.77 a          |
| $P$        | 0.273                                   | 0.002                         | 0.001                            | <0.0001          | 0.014                         | <0.0001                     | 0.0002          |

*Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

*Photosystem II (PSII) efficiency. It is the fraction of absorbed PSII photons that are used in photochemistry and is used as an indicator of plant stress.

Light level may affect soil microbial populations under natural and field conditions. The densities of *Pythium* spp. have been found to decrease under forest canopy gaps (Reinhart et al., 2010). Incidence of Phytophthora blight has been reported to decrease with increased shade level in bell pepper (Díaz-Pérez, 2014). In the present study, it is unclear whether the influence of shade on incidence of Phytophthora blight was due to a direct effect of light level on the pathogen, the host, or their interaction with the environment.

The influences of shade nets on plant diseases are little understood. In pepper, under colored shade nets, leaf coverage by powdery mildew (*Leveillula taurica*) was found to augment with increasing shade level; black, blue-silver, green, and red nets were associated with reduced powdery mildew levels (Elad et al., 2007). Interestingly, the incidences of southern blight and Tomato spotted wilt in the present study were unaffected by shade treatments, indicating that bell pepper plant diseases may respond differently to shade conditions (i.e., light quantity and quality). Shade nets probably provided some relief from plant water stress to infected plants having restricted capacity for water uptake and transport due to an impaired vascular system (Aguirreolea et al., 1995).

Gas exchange. In 2015, leaf net photosynthesis and $g_s$ were highest under silver net and lowest in unshaded conditions (Table 5). Internal CO$_2$ concentration and PSII efficiency were lowest in unshaded conditions. The $WUE$ was not significantly different among treatments. The $PAR$ ranged from 1851 µmol·m$^{-2}$·s$^{-1}$ in the unshaded treatment to 985 µmol·m$^{-2}$·s$^{-1}$ in the black net treatment. Leaf temperature was highest in the white net and unshaded treatments. In 2016, net photosynthesis was unaffected by shade net treatments (Table 6). Stomatal conductance and internal CO$_2$ were highest under the red net and among the lowest under unshaded conditions and the white net. The PSII efficiency was highest under the white net and lowest in unshaded conditions. The $WUE$ was increased in unshaded conditions. The $PAR$ ranged from 1991 µmol·m$^{-2}$·s$^{-1}$ in the unshaded treatment to 1051 µmol·m$^{-2}$·s$^{-1}$.
in the black treatment. Leaf temperature was highest in the unshaded treatment and lowest under the red net.

Mean leaf temperature at midday increased with increasing PAR under the nets ($r^2 = 0.596; P = 0.009$). However, when data from unshaded conditions were not considered in the statistical analysis, leaf temperature showed no relationship with PAR under the nets, indicating that leaf temperature had no relationship with the differences in PAR among mulches. Leaf net photosynthesis, $g_s$, internal CO$_2$, and PS II efficiency decreased with increasing values of leaf temperature (Fig. 2). Leaf net photosynthesis increased with increasing rates of leaf $g_s$ (Fig. 3). Photosystem II efficiency decreased with increasing PAR values (Fig. 4). Among shade nets, there was no relationship between internal CO$_2$ and PAR.

Leaf gas exchange responses in the present study were probably highly influenced by leaf temperature. Differences in leaf temperature among shade net treatments are because of differences in solar radiation captured by leaves. Little IR is absorbed by leaves at wavelengths below 2000 nm, but more than 97% of solar radiation is absorbed at wavelengths above 7000 nm (Larcher, 1995).

Photosynthesis can be controlled by stomatal and nonstomatal factors (Jones, 1992). Occurrence of high leaf temperature was probably associated with high solar radiation and plant water stress due to low leaf transpiration and low $g_s$. The linear relationship between net photosynthesis and $g_s$ in the present study indicates that there was a large stomatal control of photosynthesis under the various PAR levels. In a field study on bell pepper under different shade levels, net photosynthesis, transpiration, $g_s$, and water use efficiency decreased quadratically and internal CO$_2$ concentration and PSII efficiency increased quadratically with increased shade level. The authors concluded that leaf gas exchange responses were also highly dependent on stomatal factors (Díaz-Pérez, 2013). In a study on lemon trees ($Citrus limon$), shaded trees had reduced transpiration (sap flow), reduced trunk shrinkage, reduced leaf water potential, and increased water-use efficiency, indicating that shaded trees showed decreased water stress compared with unshaded trees (Alarcon et al., 2006).

Table 7. Effect of colored shade nets on leaf chemical composition in bell pepper (Tifton, GA, Spring 2015 and 2016).

| Shade    | Carotenoids (mg·L$^{-1}$) | Chl a’ (mg·L$^{-1}$) | Chl b’ (mg·L$^{-1}$) | Chl a/b | CUPRAC$^*$ (μM) | TEAC$^*$ (μM) | Total phenols [gallic acid equiv. (mg·L$^{-1}$)] | Flavonoids [Quercetin equiv. (mg·mL$^{-1}$)] |
|----------|---------------------------|----------------------|----------------------|---------|-----------------|-------------|--------------------------------------------|------------------------------------------|
| Black    | 1.10 ab$^*$               | 4.47 bc              | 2.00                 | 2.28    | 8153 c          | 13606 d     | 714 c                                     | 456 b                                    |
| Red      | 1.19 a                    | 4.84 a               | 2.13                 | 2.28    | 10093 a         | 23425 a     | 1016 a                                    | 798 a                                    |
| Silver   | 1.17 a                    | 4.79 a               | 2.10                 | 2.30    | 8867 b          | 11372 c     | 794 b                                     | 472 b                                    |
| White    | 1.18 a                    | 4.71 ab              | 2.04                 | 2.33    | 8174 c          | 19615 c     | 720 c                                     | 491 b                                    |
| Unshaded | 1.06 b                    | 4.31 c               | 1.90                 | 2.35    | 9981 a          | 22008 b     | 1017 a                                    | 767 a                                    |
|          |                           |                      |                     |         |                 |             |                                             |                                          |
| P        | 0.025                     | 0.0015               | 0.143                | 0.170   | <0.0001         | <0.0001     |                                            |                                          |

*Means followed by the same letter are not significantly different based on Fisher’s protected least significant difference test at 95% confidence.

$^*$Chl a = Chlorophyll a; Chl b = Chlorophyll b.

$^*$CUPRAC = cupric reducing antioxidant capacity.

$^*$TEAC = trolox equivalent antioxidant capacity.
Leaf chemical composition. Leaf total carotenoids were lowest in unshaded conditions and there were no differences in total carotenoids among the shade nets (Table 7). Chlorophyll a concentrations were highest in plants under the red and silver nets and lowest in unshaded conditions. Chlorophyll b concentration was unaffected by the shade net treatments. There was positive correlation between chlorophyll a and b ($r^2 = 0.948$), while there were no relationships between chlorophyll index with either chlorophyll a or b. The chlorophyll a/b ratio ranged from 2.28 (for plants under the black and red nets) and 2.35 (unshaded plants) and was unaffected by shade net treatments.

Leaf CUPRAC values were highest in the red net treatment and unshaded treatment, while lowest under the black and white nets. TEAC values were highest in the red net treatment and was unaffected by the color of shade net. The differences in the rhizomes varied with growth stage and of the year (Rawat et al., 2014).

In conclusion, compared with unshaded conditions, shade nets resulted in improved bell pepper plant growth and leaf gas exchange. These responses were due primarily to the reduced leaf and root zone temperatures under shaded conditions, regardless of the color of shade net. The differences in plant growth and function due to color of shade net were inconsistent or minor for most plant variables.

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