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Photoselective-Light Impacts on Fruit Bagging Microclimate, Quality, and Nutrients of Peach

David Campbell, Jeffrey K. Brecht, and Ali Sarkhosh
Horticultural Sciences Department, University of Florida, 2550 Hull Road, Gainesville, FL 32611

Oscar Liburd
Entomology and Nematology Department, University of Florida, 1881 Natural Area Drive, Gainesville, FL 32608

Danielle Treadwell
Horticultural Sciences Department, University of Florida, 2550 Hull Road, Gainesville, FL 32611

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Abstract. **The use of paper or nylon bags (fruit bagging) to surround tree fruit during development provides protection from a variety of pest-disease complexes for peach without yield reduction and different-colored bags have the potential to improve fruit quality based on findings from other crops. An experiment was conducted in 2019 at two locations in central Florida on peach [*Prunus persica* (L.) Batch] 'TropicBeauty' and 'UFSun' to analyze the impact of a commercially available white paper fruit bag combined with a photoselective insert. The insert reduced the amount of light outside the spectrum range of interest for blue (400–500 nm), green (500–600 nm), or red (>600 nm) wavebands, or decreased fluence rate with a neutral density black (>725 nm) insert. Relative to ambient, temperature inside all bagging treatments during the daytime hours was increased by 5.1 °C. During the same time, relative humidity was reduced by 10.1%, but calculations revealed that the water vapor pressure was elevated only for treatments that had a plastic colored (blue, green, or red) insert. An orthogonal contrast revealed that the elevated water vapor around the fruit in a colored bag increased the concentration of chlorophyll at harvest but had no effect on other quality parameters. Compared with unbagged fruit, red-bagged fruit were 1.8 times firmer and green-bagged fruit and had a lower peel chroma. White-bagged (without photoselective insert) fruit had similar nutrient concentrations for the peel, flesh, and pit when compared with unbagged fruit. When bags remained on the fruit until harvest, anthocyanin concentration in unbagged fruit peel was double the amount in white bags and 6-fold more than the bags with color inserts. Different-colored bagging treatments did not influence insect attraction or fruit quality parameters, such as fruit size, diameter, difference of absorbance (DA) index, total soluble solids (TSS), titratable acidity (TA), pH, peel lightness, peel hue, flesh lightness, flesh hue, or flesh chroma. Relative to full sun, the colored bag treatments allowed between 3.7% (black) and 17.4% (red) of the photosynthetically active radiation (*PAR*). Additional research is needed to determine if an increase in fluence rate at specific spectral wavelengths can affect the quality for peach grown in bags in the field.**

Manually bagging peach fruit has shown promise to reduce pest and pathogen injury with minimal risk to yield reduction (Allran et al., 2019; Campbell et al., 2021; Sharma et al., 2014). Bags used in research and practice are typically constructed of paper or polypropylene. The physical covering changes the environment in the area surrounding the fruit, or the carposphere, and the associated alterations in light, temperature, and humidity can affect fruit quality. Several studies have identified specific wavelengths of light that stimulate photoreceptors, which may improve fruit quality attributes such as size, color, TSS, anthocyanin content, and other quality factors (Folta and Carvalho, 2015; Holopainen et al., 2018; Olle and Viršile, 2013).

Plants contain chlorophyll that converts light into chemical energy, but light does more than provide energy for metabolism. Plants contain specific pigments, namely the phytochromes, cryptochromes, phototropins, and other photoreceptors that are activated by specific light wavelengths, and drive discrete changes in gene expression, physiology, and metabolism. These photoreceptor classes are activated in response to specific wavebands, but taken as a whole have activity from the ultraviolet (Magerøy et al., 2010; Reyes et al., 2020), visible, and near infrared (Johnson et al., 1996) spectra. Plant growth, development, morphology, and metabolism may be altered by enhancing or omitting wavelengths, as demonstrated using light-emitting diode (LED) technology (Olle and Viršile, 2013), as well as with colored nets (Manja and Aoun, 2019), reflective mulches (Kasperbauer, 2000), or bags (Sharma et al., 2014). Research using LED technology has provided the most detailed information on plant responses because narrow-bandwidth light can be projected in a controlled indoor environment to isolate plant responses. Reviews on photoreceptor activity and biochemical reactions (Folta and Carvalho, 2015), as well as phytochemical production (Holopainen et al., 2018; Olle and Viršile, 2013), detail the impact LED technology can have on protein structural changes, secondary metabolite accumulation, vegetative growth, reproductive growth, nutrient uptake, and plant defenses. For example, lettuce (*Lactuca sativa*) leaves accumulated more Cu, Fe, K, Mn, and Zn under red LED lights. Under red + blue or white LED lights, N and Mg nutrient concentrations were increased in lettuce (Amoozgar et al., 2017). In far red light, hypocotyl elongation was observed in squash (*Cucurbita maxima* × *Cucurbita moschata*) (Yang et al., 2012) and tomato (*Solanum lycopersicum*) (Chia and Kubota, 2010). Under red light, anthocyanin concentration was increased for strawberry (*Fragaria* ×*ananassa*) (Miao et al., 2016) and cabbage (*Brassica oleracea*) (Mizuno et al., 2011), but showed mixed results for lettuce (Li and Kubota, 2009; Samuolienė et al., 2012; Stutte et al., 2009). Both blue and green light decreased anthocyanin concentration in strawberry (Miao et al., 2016).

Measuring plant responses to changes in specific wavebands for field-grown tree crops is more complicated than for crops grown in controlled environments due to the diurnal light changes, unpredictable weather, and other practical difficulties. Techniques such as whole tree netting for field-grown tree crops (Mupambi et al., 2018) and bagging individual fruit (Sharma and Sanikommu, 2018) have been evaluated under different photoselective light conditions. Like netting, LED lighting affects the entire plant or tree, whereas bagging only affects the carposphere around the fruit. Different construction materials used for either netting or bagging can effectively change the spectrum of light that reaches the plant (Bastías and Corelli-Grappadelli, 2012). Shahak et al. (2004) found that netting peach trees with blue or red nets decreased the canopy temperature. Blue and white nets had no effect on fruit weight, whereas red netting increased fruit weight and both white and red nets increased vegetative growth.

In studies with apple, it was found that paper bagging increased internal bag temperatures (Ritenour et al., 1997). In peach bagging studies in which plastic bags with perforations were evaluated, it was found that relative humidity (RH) and temperature increased in the bag (Li et al., 2001; Morandi et al., 2010). The increased RH was associated with reduced transpiration and smaller fruit weight, which the authors speculated was due to a reduced xylem flow and lower sugar loading in the fruit (Morandi et al., 2010). Liu et al. (2015) found that peach anthocyanin content was reduced for black, blue, and gray bags, but was increased for white bags and unbagged fruit. Zhang et al. (2015) found that white paper and polypropylene bags resulted in similar amounts of anthocyanin when the bags remained on the fruit until harvest, and showed an increased amount of anthocyanin when black bags were removed 7 d before harvest. White-bagged peaches showed mixed results for fresh weight, chlorophyll content, organic acids, TSS, firmness, and peel color (Liu et al., 2015; Zhang et al., 2015).

In addition to potentially altering the fruit quality, different colors also impact insect pest attraction. Different-colored traps have been shown to attract beneficial lady beetles (Coleoptera: Coccinellidae) (Kemp and Cottrell, 2015) and stink bug pests (Hemiptera: Pentatomidae) (Bae et al., 2019; Hogmire and Leskey, 2006), but no effect was found when different-colored traps were placed in commercial peach orchards (Leskey and Hogmire, 2005). There is limited research on the attraction of arthropod pests to a wide range of colors in peach orchards and identifying offsetting effects of fruit quality changes with increased pest attraction will be useful practical information for growers.

There are extensive reports that demonstrate the positive impacts of reducing pest and disease injury for a variety of crops and the ability to alter plant physiology under different bagging and light conditions. The contribution of the current study is the evaluation of the impact of a wide range of modified light spectra conditions on peach fruit quality and insect attraction. The purpose of this project was to determine if different-colored bags alter the temperature, RH, fruit quality, and known arthropod pest attraction for low-chill peach cultivars. This project tested the hypothesis that selective color filters within bags in the field can be used to affect the fruit quality of peach, such as increased anthocyanin for blue and red filters, decreased anthocyanin for black and green filters, and increased fruit size for red filters (Holopainen et al., 2018; Liu et al., 2015; Shahak et al., 2004; Wang and Folta, 2013). Parameters including temperature and RH inside the bag, insect attraction, and fruit quality parameters such as fresh weight, size, chlorophyll content, TSS, TA, pH, flesh firmness, anthocyanin concentration, peel color, flesh color, and nutrient concentration were analyzed to determine if bagging can provide growers with a practical means to improve fruit quality.

Materials and Methods

Experimental sites. Research station and on-farm trials were conducted with 'TropicBeauty' and 'UFSun' peaches on 'Flordaguard' rootstock at a conventional peach orchard at the University of Florida/Institute of Food and Agricultural Science (UF/IFAS) Plant Science Research and Education Unit in Marion County, FL (lat. 29.408813°N, long. 82.173041°W, altitude 21 m) and with 'TropicBeauty' peach on 'Flordaguard' rootstock at a U.S. Department of Agriculture–certified-organic peach orchard in Lake County, FL (lat. 28.608826°N, long. −81.750942°W, altitude 34 m) in 2019. The soils at both locations were deep and well drained with less than 2% soil organic matter and classified as a Sparr fine sand series soil type (loamy, siliceous, subactive, hyperthermic Grossarenic Paleudults) at the Marion County location and the Candler sand series soil type (Hyperthermic, uncoated Lamellic Quartzipsamments) at the Lake County location.

At the Marion County location, 'TropicBeauty' and 'UFSun' were planted in 2012 with a higher than typical density planting averaging 785 trees/ha. The orchard received 1121 $\text{kg}\cdot\text{ha}^{-1}$ of granular 10N–0.4P–0.8K in three band applications and four foliar micronutrient applications at 9.35 $\text{L}\cdot\text{ha}^{-1}$ (SOAR Peach Mix; Chemical Dynamics, Inc., Plant City, FL). For weed, insect, and fungal management, the site received monthly applications of 630 $\text{g}\cdot\text{ha}^{-1}$ a.i. of paraquat dichloride (Parazone 3SL Herbicide; AMVAC, Los Angeles, CA), three applications of 140 $\text{g}\cdot\text{ha}^{-1}$ a.i. of spirotetramat (Movento; Bayer CropScience, Monheim am Rhein, Germany), and two applications of 1684 $\text{g}\cdot\text{ha}^{-1}$ a.i. of chlorothalonil (Bravo; Syngenta, Basel, Switzerland), respectively. Only 'TropicBeauty' was evaluated at the Lake County site, and the layout and management have been previously described by Campbell et al. (2021). In short, the trees were planted to a density of 289 trees/ha and managed as a certified-organic U-pick orchard with the same N rate applied as at the Marion County location and organic compliant fungicides and pesticides.

Experimental design. The initial experimental design consisted of two factors: cultivar (2 levels: 'UFSun' and 'TropicBeauty') and bag color (6 levels: see the following) at two locations, with treatments arranged in a completely randomized design with six replicates (individual trees served as a replicate). However, the field cultivar map used at the time of bagging was incorrect and due to the similarity of phenology between 'UFSun' and 'TropicBeauty', the cultivars were misidentified and only 'TropicBeauty' was bagged at the Lake County site. The error was recognized halfway through the season. and although the resulting design was imbalanced in its representation of cultivars, a modified approach to statistical analysis was developed in consultation with a statistician. The modified design assessed bag removal for 'TropicBeauty' at two levels [7 d before harvest (DBH) and at harvest (0 DBH)] at the Lake County site only. Cultivars were correctly identified and bagged at the Marion County site. The final experimental design included the factors cultivar (2 levels) and bag color (6 levels) at the Marion County site and bag removal (2 levels) and bag color (6 levels) at the Lake County site. The experiment consisted of four different location/cultivar/bag removal combinations (heretofore referred to as a site combination). At each site, replications consisted of a single tree with all factor combinations and fruit from 12 trees at each site were assessed.

At each site combination, the main factor of bag color was randomly assigned to eight individual fruit per tree at six levels: no bag (control), white paper (WP) bag only, and four color levels (blue, green, red, and black) that consisted of the WP bag with a 20 cm × 10 cm photoselective colored film or a polyester microfiber insert (Fig. 1). Microfiber

Fig. 1. Photographs taken in the field of colored bagging treatments with the background photograph outside of the bag, top right taken inside the bag with a telescopic camera, and bottom right taken of the color-baited insect traps of the unbagged control (**A**), white paper bag (WB) only (**B**), black insert + WB (**C**), blue insert + WB (**D**), green + WB (**E**), and + WB (**F**). Photo courtesy of author, D. Campbell.

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D.T. is the corresponding author. E-mail: ddtreadw@ufl.edu.

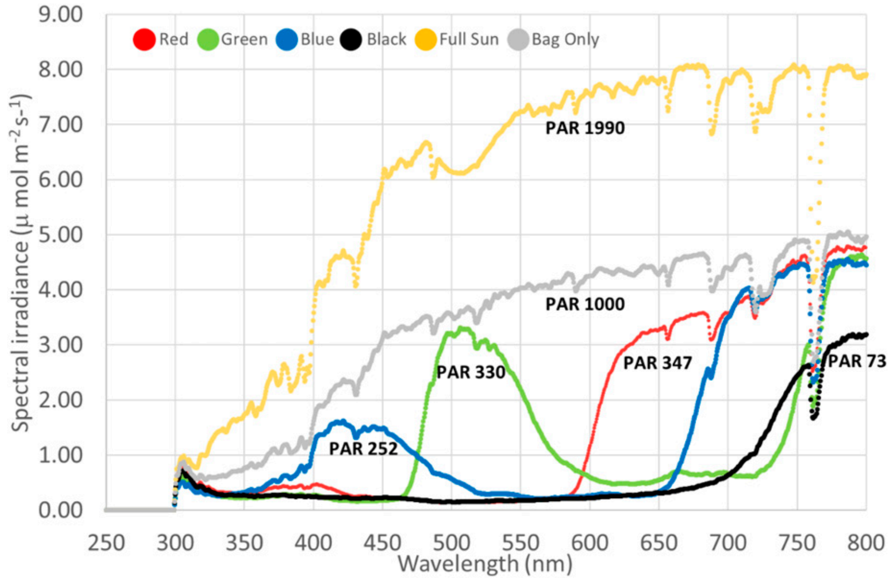

Fig. 2. Spectral irradiance of full sun, white paper bag only (bag only), and photoselective inserts while inside a white paper bag for the treatments: red, green, blue, and black. Photosynthetically active radiation (*PAR*) values listed below each measurement.

was used for the black treatment because the desired spectrum was not available in plastic film and the hydrophobic nature of microfiber would avoid moisture retention within the bag, which was similar to the other photoselective inserts. The total *PAR* and transmitted light spectrum through the WP bag plus photoselective insert (Fig. 2) was verified to confirm wavelengths outside of the range of interest were reduced for treatments with relatively increased wavelengths at 400 to 500 nm, blue (roscolux #4290; Rosco, Stamford, CT); 500 to 600 nm, green (roscolux #389); >600 nm, red (roscolux #26), and >725 nm, black (black microfiber; American Home Collection, Maspeth, NY) by a spectroradiometer (Apogee/Stellarnet, Logan, UT).

Bag installation and harvest. Full bloom for ‘UFSun’ was observed on 24 Jan. 2019 and between 29 and 31 Jan. 2019 for ‘TropicBeauty’. Fruit were thinned according to standard grower practices (Chang et al., 2018). Within 3 d of protective insecticide and fungicide applications (see earlier in this article), eight fruitlets that measured between 3 and 4 cm along the stem-blossom axis were bagged between 28 Feb. 2019 and 11 Mar. 2019. The sequence of bagging level and direction traveled around the tree was randomly assigned for each tree resulting in a random and even distribution of color treatments around the canopy perimeter. Fruit were bagged on the tree’s outermost perimeter at a height between 1 and 2 m and the photoselective material inside the bag was manually rotated to ensure that incident light would pass through the photoselective filter before reaching the peach surface (Fig. 1). Unbagged fruit were identified by wrapping pink tape around the branch proximal to the selected fruit (Fig. 1). In general, ‘UFSun’ matured ≈10 d before ‘TropicBeauty’, and the more southerly Lake County site matured 9 d before the Marion County site. Bagging procedures were previously described by Campbell et al. (2021). Based on grower recommendations, tactile observations of softening fruit tips, increased blush of unbagged fruit, and decreased chlorophyll readings for all site combinations that included a bag removal 7 DBH (DA Index below 40 was determined optimal based on research and observations conducted in 2018), three harvests of tree-ripened fruit occurred between 23 Apr. 2019 and 9 May 2019, and the fruit were transported in a climate-controlled vehicle to the Postharvest Physiology Laboratory at UF/IFAS (Gainesville, FL).

To test insect pest attraction to these color levels, photoselective inserts were inserted inside double-conical insect traps that effectively capture stink bug pests (Hemiptera: Pentatomidae) (Fig. 1). Three replications (18 total color-baited traps) were installed on ‘TropicBeauty’ scaffold branches at the Lake County location. Color-baited insect traps were monitored every 2 weeks.

Meteorological, soil, and leaf nutrient data. Weather data for 2018 and 2019 were collected from the closest Florida Automated Weather Network (FAWN, 2019) weather station for the Lake County location (28.681 650°N, −81.885650°W, altitude 27 m), which was located ≈15.5 km northeast of the orchard and onsite at the Marion County location. Measurements and associated comparisons of temperature, RH, and water vapor pressure inside the colored bag treatments were collected with temperature/RH sensors (HOBO MX2302A; Onset Computer, Bourne, MA) that had an air and dew point temperature accuracy of ±0.2 °C and RH accuracy of ±0.25%. A single sensor for all treatments was installed on three replicates of ‘UFSharp’ trees (18 sensors in total), which provided information beyond the maturation dates of ‘UFSun’ and ‘TropicBeauty’. Sensors were installed on 21 Mar. 2019 under the filter and above the fruit to avoid shading and remained inside the bag throughout the duration of the season until removal on 17 May 2019. Sensors that served as an unbagged control were placed adjacent to fruit on the same tree and were installed with a sun-shield as recommended by the manufacturer to ensure the integrity of the sensor. Dew point temperature collected from the sensors was used to calculate the amount of water vapor pressure (WVP) inside the bags based on a formula provided by the National Weather Service National Ocean and Atmospheric Administration (https://www.weather.gov/epz/wxcalc_vaporpressure) as outlined in the following equation:

$$\mathrm{WVP} = 6.11{*}10\,\hat{}\,(7.5 * \mathrm{T_d}/237.3+\mathrm{T_d}),$$

where WVP = water vapor pressure, and $\mathrm{T_d}$ = dew point temperature.

Soil and leaf tissue nutrient analyses were conducted immediately after fruit harvest to determine nutrient status and eliminate any confounding factors (data not shown but will be available online at the UF dissertation repository in 2023). At each site combination, 10 soil cores collected with a 2.5-cm diameter probe to 10 cm deep were bulked, mixed, and submitted to the UF/IFAS Analytical Research Laboratory (Gainesville, FL) for analysis with a Mehlich-3 extraction. At each site combination, 30 first-fully expanded mature leaves and petioles from each tree were collected and submitted for nutrient analysis (Waypoint Analytical Laboratory, Mulberry, FL).

Fruit physical, compositional, and nutrient analysis. Three fruit from each color treatment were harvested within ≈3 d of being ripe and ready for consumption. Transport from orchards to laboratory and procedures for fruit quality analyses of weight, diameter, peel color, flesh color, chlorophyll content, flesh firmness, pH, TSS, and TA measurements were identical to those described in Campbell et al. (2021). Peel and flesh color measurements of lightness, hue, and color were directly reported or calculated according to the CIE L*a*b scale. In short, measurements (by instrument) of weight (Mettler Toledo, Columbus, OH), diameter (EW-97152; Cole-Parmer, Vernon Hills, IL), peel color (Minolta CR-400; Marunouchi, Chiyoda, Tokyo, Japan), and DA Index (DA Meter; Sinteleia, Bologna, Italy) were taken on the day of harvest and after storage at 3 °C for up to 48 h. Fruit were allowed to warm to room temperature, peeled to expose a circular area ≈2.5 cm in diameter, assessed for flesh color and firmness (TA HD plus texture analyzer; Texture Technologies, Inc., Hamilton, MA), peel tissue collected for anthocyanin analysis (see anthocyanin analysis in the next section), and two longitudinal slices along the stem-blossom axis were removed and stored at −30 °C. Within 30 d, fruit slices were thawed but kept cold and then blended (commercial blender; Hamilton Beach, Glen Allen, VA) and the resulting slurry was centrifuged at 22,217 g_n at 4 °C for 10 min and the supernatant (juice) was decanted.

Measurements of pH and TA (814 USB Sample Processor; Metrohm, Herisau, Switzerland), and TSS (Reichert Ametek, Berwyn, PA) were performed using the supernatant.

Anthocyanin analysis. Peaches were peeled to a depth of 1 mm along the midpoint of the stem-blossom end around the entire circumference of the peach. Additional peel that was most representative of overall peel color was collected to yield 5 ± 0.5 g and stored at −30 °C. Anthocyanin extraction (modified from Lee et al., 2005) and measurements were conducted under a yellow light that reduced the degradation of anthocyanin. Before peach sample preparation, the extraction solution [370 mL deionized (DI) water, 30 mL formic acid, and 600 mL methanol], a solution at pH 4.5 (880 mL DI water, 54.4 g sodium acetate, 20 mL 1.5N HCl), and a solution at pH 1.0 (990 mL DI water, 1.86 g KCl, 8.3 mL 1.5N HCl), were prepared and stored at 2 °C. Before extraction, the frozen peach peel was thawed but kept on ice while not being processed. Thawed peel (1.5 ± 0.15 g) was homogenized (OMNI bead rupter elite homogenizer; OMNI International, Kennesaw, GA) in 15 mL of the extraction solution. Successful homogenization was achieved when, on visual observation, the peel was uniformly disassociated, and homogenate peel pieces were less than 2 mm wide. The homogenate and solution were left to passively extract the anthocyanin for 20 min while in an ice bath. Next, the solution was centrifuged at 15,428 g_n at 4 °C for 10 min and 0.3 mL of supernatant was pipetted into prefilled test tubes (containing 2.7 mL of either the pH 4.5 or pH 1.0 solution). The combined supernatant and pH 4.5 and 1.0 solutions were vortexed for 20 s and allowed to equilibrate for 15 min at room temperature (24 °C). After equilibration, 200-μL samples of the supernatant-pH solution samples and deionized water blanks were loaded into non-ultraviolet–compatible microplates. Microplates were loaded into a Powerwave XS2 spectrophotometer (BioTek Instruments, Inc., Winooski, VT) and the absorbance was read at 510 nm and 700 nm with a path-length correction. The concentration of the most prominent anthocyanin in peach fruit, cyanidin-3-glucoside (C-3-G), was calculated based on the approach described by Lee et al. (2005) and Jurd and Asen (1966), as outlined in the following equation:

$$\text{C-3-G}(\text{mg}\cdot\text{L}^{-1}) = (\text{A} * \text{MW} * \text{DF} * 1000)/\text{L} * \alpha,$$

where A (absorbance) = [A510(pH1) – A700(pH1)] – [A510(pH4.5) – A700(pH4.5)]; MW (molecular weight) = 449.2 g·mol^{-1} for C-3-G; DF (dilution factor) = (solvent + peel) / (peel * (pH solution + supernatant)/ supernatant); L = 1 cm; and α = 26,900 L·mol^{-1}·cm^{-1}.

Nutrient analysis. Two ‘TropicBeauty’ fruit from the white-bagged (removed 7 DBH) and unbagged control from each replication at both locations were selected for nutrient composition analysis. Fruit peel was removed to a depth of 1 mm and flesh was separated from pits for all fruit before drying in a forced-air oven at 65 °C until dry (at a constant weight). Dried peel and flesh samples were unprocessed, but dried pit samples were ground to less than 1 mm using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) before nutrient analysis (Waypoint Analytical Laboratory, Mulberry, FL).

Statistical analyses. Linear mixed model assumptions of linearity, normality, and homogeneity of variance were satisfied before analysis of variance (ANOVA). Two ANOVAs were conducted, the replicated site combination of ‘TropicBeauty’ with the bag removed 7 DBH and each single-site combination analysis using the GLIMMIX procedure of SAS (v 9.4; SAS Institute, Cary, NC). The statistical model for the single-site combinations was improved by analyzing variables that had covariance parameters with a χ^2 at $P \leq 0.05$ separately to account for heterogeneity between site combinations. Temperature, RH, and WVP were analyzed as a contrast between each colored bag and the control. When significant at $P \leq 0.05$, means were separated using Tukey’s honestly significant difference method. Differences and interactions between cultivar and bag removal date factors were not analyzed because they would not provide additional information regarding the effects of different color treatments.

Results

Site conditions. The orchard naturally defoliated by 1 Dec. 2018, and the first budbreak was observed on 10 Jan. 2019. During dormancy, the orchards received 67 and 105 h between 0 °C and 7.2 °C in Lake County and Marion County locations, respectively. The average air temperature (measured at 2 m above the ground) and the average daily temperature and total precipitation for the growing cycle between full bloom and the first harvest were 18.0 °C and 307.6 mm at the Marion County location and 19.4 °C and 207.3 mm at the Lake County location (Fig. 3). Soil and leaf nutrient levels from field-collected samples indicated that nutrient deficiency was not a limiting factor at either location (Johnson, 2008; data not shown but will be available

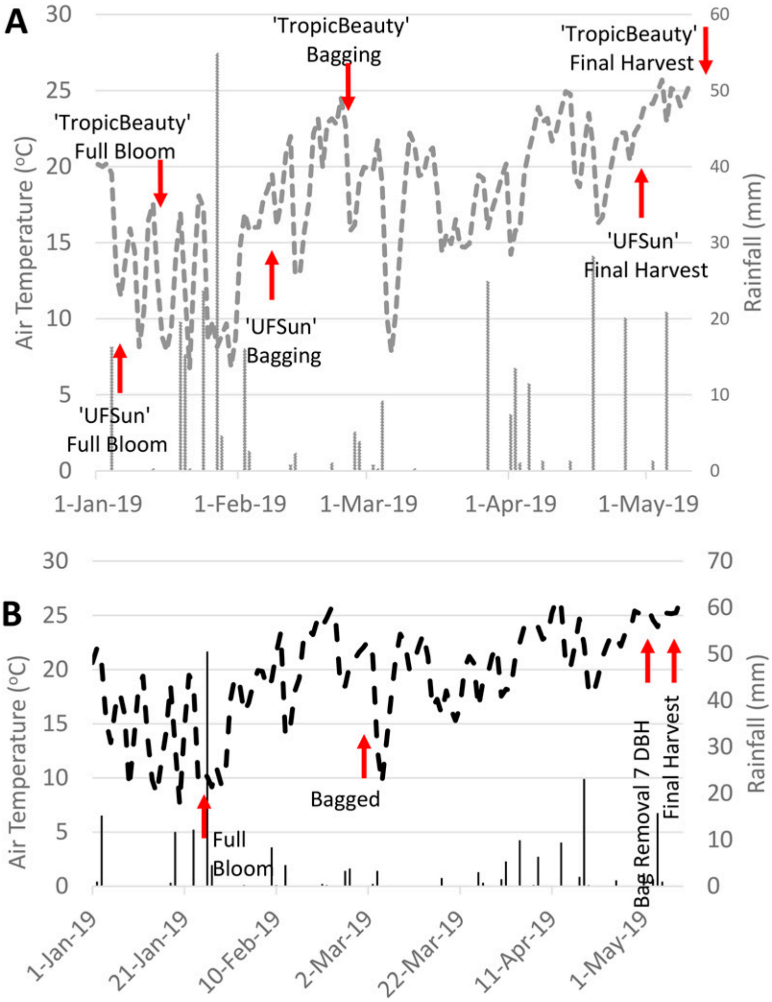

Fig. 3. Average daily temperature and rainfall in central Florida during peach fruit growth in (**A**) Marion County (1 Jan. 2018 to 10 May 2018), with arrows representing dates corresponding to full bloom, bagging date, and the final fruit harvest for ‘UFSun’ and ‘Tropic Beauty’; and (**B**) Lake County (1 Jan. 2019 to 10 May 2019), with arrows representing dates corresponding to full bloom, bagging date, bag removal at 7 d before harvest (7 DBH), and the final fruit harvest.

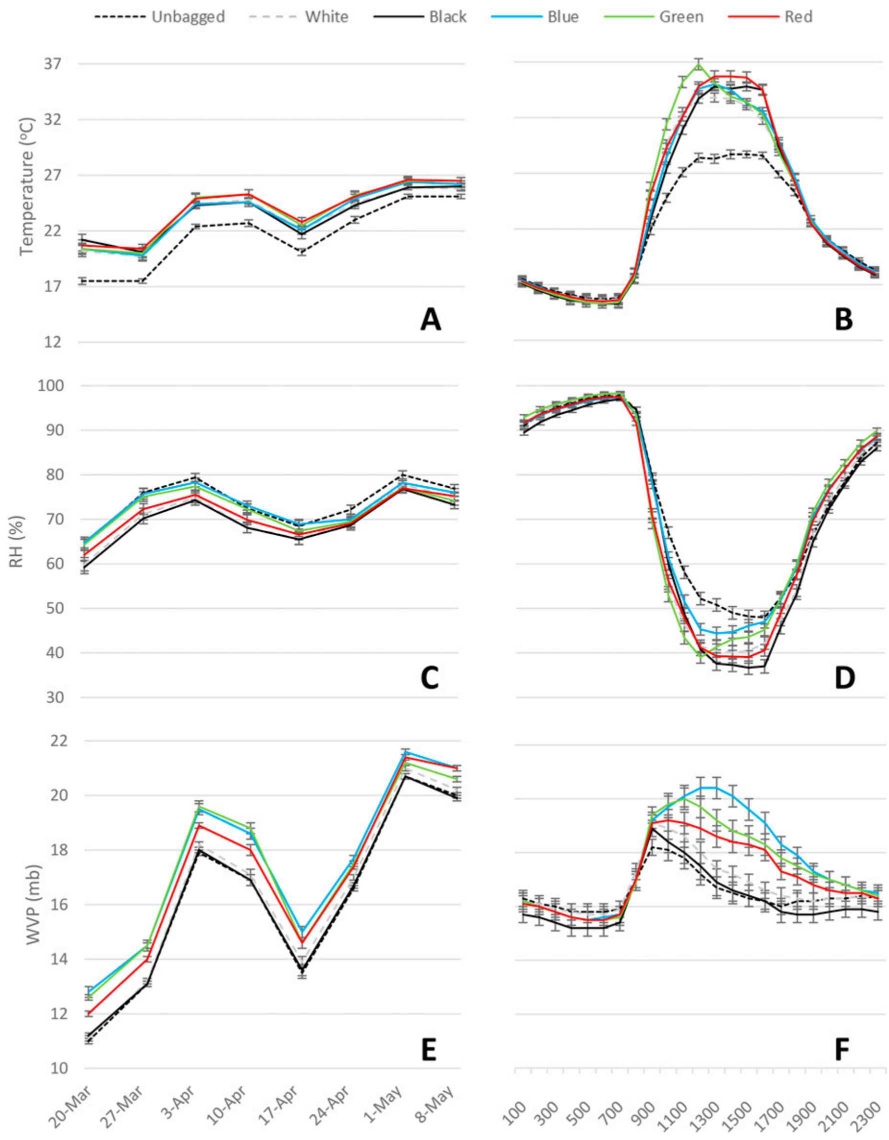

Fig. 4. Temperature (**A** and **B**), RH (**C** and **D**), and water vapor pressure (WVP) (**E** and **F**) around unbagged 'UFSharpe' peach fruit and inside bags containing fruit grown in Marion County in 2019. Data were averaged by week (left column) and over the year, and presented on an hourly basis (right column). Data are presented as means with bars representing the SE. Differences ($P \leq 0.05$) are discussed in the text.

online at the UF dissertation repository in 2023).

Air temperature, RH, and WVP in bags. When averaged over a weekly basis, the internal bag temperatures for all treatments were consistently elevated throughout the growing season ($P \leq 0.05$), but the magnitude of temperature increase declined throughout the season for all treatments (Fig. 4). For example, the internal white bag temperature was 3.3 °C higher than the control outside air temperature during the week of 20 Mar. 2019, but was only 0.8 °C higher than the control during the week of 9 May 2019. Temperatures averaged across the entire season and analyzed on an hourly basis inside the bags were consistently elevated between 900 HR and 1800 HR for all treatments ($P \leq 0.033$) except for the black at 0900 HR ($P = 0.086$). The sun rose between 0638 HR and 0724 HR over the course of the experiment and the average temperature increase inside all bags was 5.1 °C (Fig. 4). Relative to ambient, the average RH levels inside the bags were generally reduced for all treatments throughout the study. In the early season (between 28 Mar. and 17 Apr.), the RH levels within the white ($P < 0.05$), black ($P < 0.01$), and red ($P < 0.05$) bags were lower than ambient. Later in the season (between 25 Apr. to 8 May), black ($P < 0.05$), green ($P < 0.05$), and red ($P < 0.05$) had lower RH than ambient (Fig. 4). On an hourly basis, all treatments had a reduced RH from 1000 HR to 1400 HR ($P \leq 0.036$), averaging 10.1% lower RH than ambient. Reduced RH was observed immediately outside of this time frame for one or multiple treatments from 0800 to 1800 HR (excluding blue) ($P \leq 0.036$). Relative to the ambient the average WVP was increased for the blue, green, and red treatments for the entire experiment ($P \leq 0.001$). On an hourly basis, WVP was increased for blue, green, and red from 1000 HR to 1800 HR ($P \leq 0.032$).

Fruit physical and compositional attributes. The pairwise comparison of 'TropicBeauty' at two locations with the bag removed 7 DBH revealed that most physical and compositional characteristics did not change in response to bag color (Tables 1 and 2), but differences were observed between sites. There were no significant interactions between bag color and location for any measured fruit physical and compositional attributes. Fruit in red bags were 1.8 times more firm than unbagged fruit. Fruit peel chroma (a measure of color saturation or intensity) was greater for unbagged fruit than for green-bagged fruit (Table 1). Fruit from Marion County were 5.1 mm larger in diameter ($P \leq 0.001$), 22 g heavier ($P \leq 0.001$), and had 2.5% lower TSS ($P \leq 0.001$) than fruit from Lake County. Fruit from Marion County also had slightly higher color measurements of peel chroma ($P = 0.012$), flesh chroma ($P = 0.005$), and flesh lightness ($P \leq 0.001$). Bag color and growing location did not impact DA Index, TA, pH, anthocyanin concentration, peel lightness, peel hue, and flesh hue.

Analysis at each site combination level revealed no differences between the cultivars grown in Marion County. In Lake County, only flesh firmness showed differences when the bags were removed 7 DBH. At this site combination, green- and red-bagged fruit were ≈2.4 times firmer than the control ($P = 0.004$) (Fig. 5). When bags remained on the fruit until harvest (0 DBH), multiple differences were observed. The unbagged control had double the anthocyanin content of the white-bagged group and ≈6 times more than the other colored bags ($P = 0.002$) (Fig. 5); all bagging treatments had lighter peel than the control, and all colored bag treatments were lighter than the white bag ($P \leq 0.001$) (Fig. 5); in addition, all bagging treatments had a greater peel hue (more yellow) than the control ($P \leq 0.001$) (Fig. 5). Peel chroma showed a pattern that was similar to peel hue for all colored bagging treatments ($P = 0.003$) (data not shown). At each site combination level, bag color did not affect fresh weight, fruit diameter, DA Index, TSS, TA, pH, flesh lightness, or flesh hue.

Peach peel, flesh, and pit nutrient analysis. Peach peel and flesh nutrient content was unaffected by bagging color or by a bagging color*location interaction. Peel nutrient analysis showed 34% to 43% greater amounts of N, S, P, K, Mg, and Mn at the Marion County location than at the Lake County location, but 389% more Cu in the peel of fruit at the Lake County location (Table 3). Flesh nutrient analysis showed 14% to 65% greater amounts of N, P, K, Mg, Ca, and B at the Marion County location than at Lake County, but 32% and 171% greater amounts of Zn and Cu, respectively, at the Lake County location (Table 3). Pit nutrient analysis showed a 33% increase in S at the Marion County location (Table 3).

Insect monitoring. Insect traps were installed on 12 Mar. 2019 and removed at final

Table 1. Physical and chemical attributes of ‘Tropic Beauty’ peach fruit grown inside white paper bags (no filter) or with photoselective filters to alter the spectrum black (>725 nm), blue (400–500 nm), green (500–600 nm), and red (>600 nm) relative to full-spectrum light in Marion and Lake Counties in central Florida in 2019.

Bag color	Fresh wt (g)	Diam (mm)	DA index[z]	TSS[y]	TA[x]	pH[w]	Flesh firmness (N)	C-3-G[v] ($mg\cdot L^{-1}$)
Control	95.8[u]	56.0	0.44	10.2	1.34	3.79	19.92 b	190.2
White	102.6	56.8	0.48	9.8	1.37	3.77	22.53 ab	186.9
Black	98.1	56.9	0.47	9.8	1.46	3.76	29.79 ab	243.8
Blue	95.6	56.0	0.60	10.3	1.52	3.72	29.68 ab	198.7
Green	87.7	54.5	0.59	10.0	1.46	3.78	33.11 ab	236.1
Red	99.8	56.7	0.54	10.4	1.45	3.77	35.70 a	211.7
SEM[t]	4.1	0.9	0.07	0.2	0.06	0.02	3.51	22.3
P value	0.174	0.378	0.403	0.239	0.295	0.474	0.012	0.332

[z] Unit less difference of absorbance (DA) index measurement of chlorophyll-α (Spadoni et al., 2016).

[y] TSS = total soluble solids.

[x] TA = total titratable acidity.

[w] pH values represent the median.

[v] C-3-G = anthocyanin concentration of cyaniding-3-glucoside.

[u] Value mean. Within columns, different letters next to treatment means indicate significant differences at $P \leq 0.05$ as calculated by Tukey’s honestly significant difference test.

[t] SEM = standard error of the mean.

harvest on 29 Apr. Zero insects were found in the color-baited traps, but predatory male and female regal jumping spiders, *Phidipus regius* C.L. Koch, were collected in green- and blue-baited traps on 26 Mar. 2019.

Discussion

Air temperature, RH, and WVP. The results of this study are consistent with peach and apple bagging studies in which increased air temperatures were observed inside fruit bags (Li et al., 2001; Morandi et al., 2010; Ritenour et al., 1997), but contrast with other studies of bagged peaches in which similar or lower internal bag air temperatures were observed (Zhang et al., 2015). In this study, all bagged fruit were on the canopy perimeter and the air temperature inside the bags exceeded 14 °C above ambient temperature during specific dates/times. The maximum observed temperatures were generally between 35 and 40 °C for all color treatments. Increased temperatures can alter stomatal aperture, photosynthetic capacity, and other responses that are species and cultivar dependent. The maximum temperatures observed would promote a higher carbon assimilation rate of Rubisco (Salvucci et al., 2001), but would not denature peroxidases (Neves and Lourenço, 1998) or polyphenol oxidase in peach (Garro and Gasull, 2010).

Low-chill peaches, such as ‘UFSun’ and ‘TropicBeauty’, can be damaged by early-season freezes that kill developing buds and fruitlets, and an increase in carposphere temperature would mitigate that risk. We did not observe any freezing temperatures in 2019, but in the early mornings on 21 Mar. and 22 Mar., the ambient temperatures fell below 5 °C for at least 15 min between 0400 HR and 0700 HR. Unfortunately, the temperature inside the bags was not elevated during this time frame, and although bags may reduce evaporative cooling of fruit during freezes accompanied by wind, early-season freeze protection is not likely.

During the harvests, the average bagging temperature was above 35 °C with an RH below 40% for at least 3 h between 25 Apr. and 1 May. Casals et al. (2010) demonstrated that an optimum postharvest curing treatment to protect peaches against the causative agent of brown rot (*Monilinia fructicola*) was a one-time treatment at 50 °C for 2 h at RH levels above 90%. They also found that protection against *M. fructicola* was observed when the temperature/RH was 40 °C/85% for 4 h and at 50 °C/65% for 2 h. Future scientists need to consider and control for bagging materials that may alter the WVP inside the bags and possibly confound the results. Information on a wider range of temperature, RH, WVP, and treatment durations to reduce *M. fructicola* growth and injury is needed to determine if the protective effects observed from bagging in Florida (Campbell et al., 2021) are due to a physical barrier preventing spore deposition on the fruit surface, a potential in situ curing with multiple days/hours at an increased temperature, or a combination of both.

The diurnal RH and temperature changes were expected, but the increased WVP in the bags that contained plastic inserts provide evidence that air flow may have been restricted. The lack of other quality changes suggests that increased WVP surrounding bagged peaches may not have any biological significance.

Shading, photosynthesis, and fruit quality. Although the higher temperature inside bags may lead to an increased activity of Rubisco and an overall increase in photosynthetic activity in the green fruit, shading counteracts these benefits (Chen and Cheng, 2007; Pavel and DeJong, 1993). The increased shading with PAR values as low as 73 $\mu mol\cdot m^{-2}\cdot s^{-2}$ in this study combined with the lack of fruit fresh weight differences suggests that the potential lack of carbon assimilation by the green fruit was likely offset by carbohydrate production elsewhere in the tree.

In addition to natural shading by the canopy, the color bagging treatments shaded fruit with *PAR* values relative to full sun of 3.7%, 12.7%, 16.6%, 17.4%, and 50.3% for the black, blue, green, red, and white treatments, respectively. The photosynthetic rate saturation for ‘Cal Red’ peach was reported to be 600 $\mu mol\cdot m^{-2}\cdot s^{-2}$ (Pavel and DeJong, 1993), but the only bagging treatment in the current study that exceeded that rate was the white bag (1000 $\mu mol\cdot m^{-2}\cdot s^{-2}$), whereas all others

Table 2. Peel and flesh color attributes of ‘Tropic Beauty’ peach fruit grown inside white paper bags (no filter) with photoselective filters to alter the spectrum black (>725 nm), blue (400–500 nm), green (500–600 nm), and red (>600 nm) relative to full-spectrum light at Marion and Lake Counties in central Florida in 2019.

	Peel			Flesh		
Bag color	L[z]	h[y]	C[x]	L	h	C
Control	48.50[w]	46.98	43.77 a	69.23	83.90	59.06
White	49.94	47.68	42.41 ab	69.73	84.32	58.66
Black	47.87	45.10	42.04 ab	71.03	85.54	56.32
Blue	48.10	45.41	41.40 ab	71.31	86.04	57.75
Green	47.22	44.18	40.23 b	70.52	85.37	57.75
Red	47.80	45.42	42.98 ab	71.05	85.42	57.94
SEM[v]	1.24	2.05	0.81	0.98	0.70	0.79
P value	0.728	0.853	0.044	0.561	0.613	0.217

[z] L = lightness range from 0 (black) to 100 (white).

[y] h = hue angle that represents color ranging from 0 to 360 degrees with colors equivalent to 0 (red), 90 (yellow), 180 (green), and 270 (blue).

[x] C = color saturation or intensity from 0 (gray) to 60 (full saturation/intensity).

[w] Values are the means. Within columns, different letters next to treatment means indicate significant differences at $P \leq 0.05$ as calculated by Tukey’s honestly significant difference test.

[v] SEM = standard error of the mean.

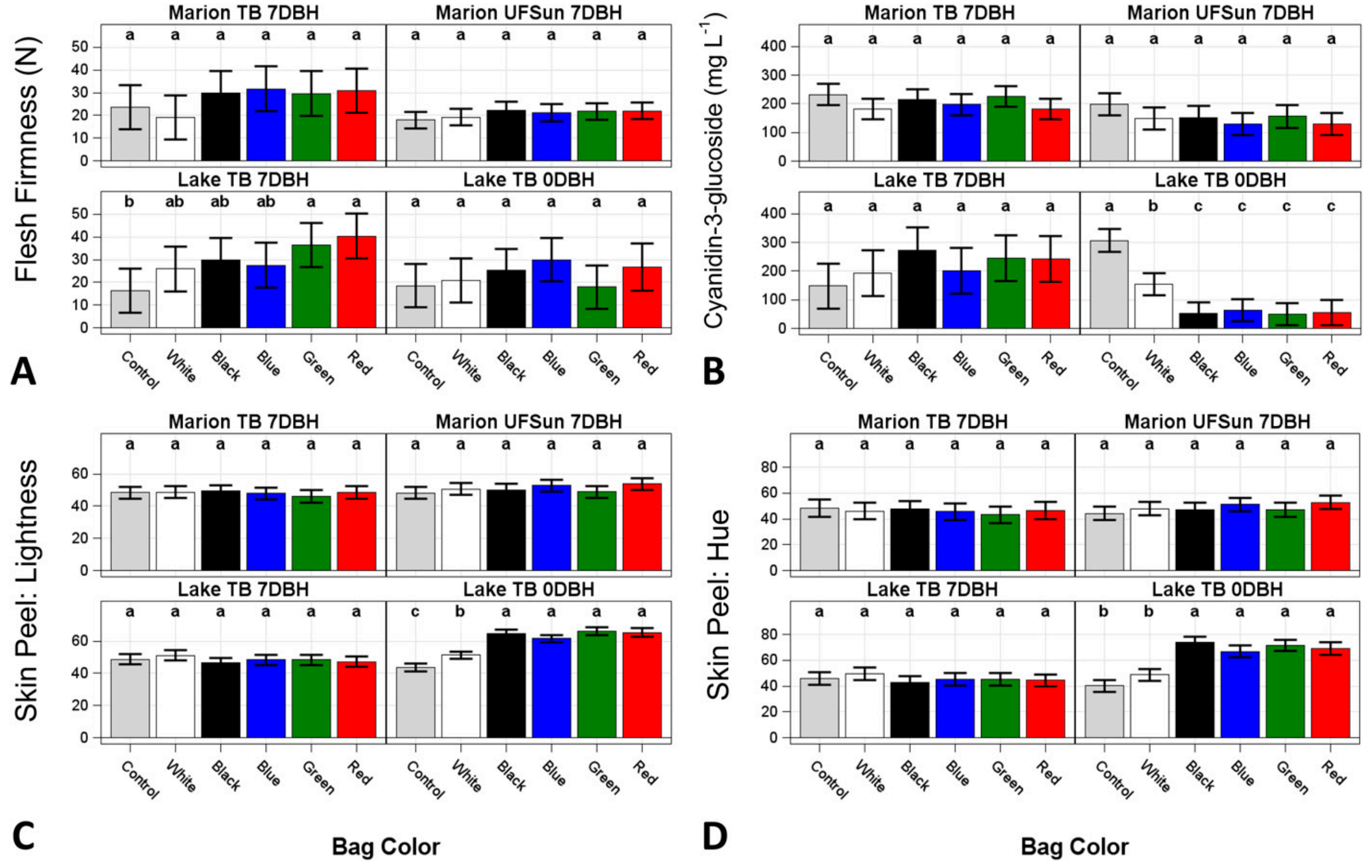

Fig. 5. Site combination above each graph for flesh firmness (**A**), anthocyanin (cyanidin-3-glucoside) concentration (**B**), peel lightness (**C**), and peel hue (**D**) for peaches grown in Marion County (Marion) or Lake County (Lake); cultivars 'Tropic Beauty' ('TB') or 'UFSun'; with bag removal at 7 d before harvest (7DBH) or not removed until harvest (0DBH) in 2019. Error bars represent the 95% confidence interval and each site combination was analyzed separately. Different letters above each mean are significantly different ($P < 0.05$) according to Tukey's honestly significant difference.

received, at most, 57.8% (red bag) of the 600 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-2}$ saturation requirement. This suggests that the color treatments were all being "grown in the dark" and contributed proportionately less to the total photosynthetic capacity of the tree, but additional research on low-chill cultivar photosynthetic saturation amounts are needed to confirm this assumption.

Fruit physical, chemical, and nutritional attributes. Using different-colored bags has shown mixed results on fruit quality for a variety of crops (Sharma et al., 2014), but the results from this experiment only showed that flesh firmness was increased when fruit were grown in red bags, and peel chroma was decreased when they were grown in green bags. Zhang et al. (2015) used white and black paper and polypropylene bags, removed the bags 7 DBH, and generally found that bagging treatments increased the peel chroma, reduced peel lightness, and reduced peel hue. Peel chroma was found to decline during postharvest, as evidenced by the reduction from 44 to 39 when low-chill 'Flordaking' peach fruit were stored at 0 ± 0.3 °C up to 5 weeks (Tareen et al., 2012). Lower chroma was associated with accelerated ripening of peach and plum fruits (Guillén et al., 2013), but it is unlikely that the fruit in green bags were ripening faster than other treatments given the high flesh firmness and DA Index values.

Compared with the unbagged control, the greater firmness observed for fruit in red bags is consistent with a numerical firmness increase for other bagging treatments in this study and some (Campbell et al., 2021; Zhang et al., 2015), but not all (Wang et al., 2010), peach bagging studies. Red light with a peak at 660 nm converts phytochrome B from the inactive form (P_r) to the active form (P_{fr}) and can be converted back to P_r with light at 730 nm, or naturally over extended periods of time without light. The red bag had a photochemical equilibration ratio of 0.84:1 (Schäfer and Nagy, 2006) and a fluence rate of 73 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in the wavelength range of 660 ± 5 nm. By comparison,

Table 3. Total nutrients of whole fruit on a dry weight basis for 'Tropic Beauty' peach grown in Central Florida (Marion or Lake County) in 2019.

		N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu
					(%)						(ppm)		
Skin	Marion	1.157	0.072	0.138	1.294	0.090	0.165	0.011	36.292	9.875	6.442	25.000	1.875
	Lake	0.812	0.053	0.102	1.074	0.063	0.059	0.011	31.167	10.250	4.708	33.542	9.167
	P value	<0.001	0.007	0.008	0.050	0.001	0.070	0.946	0.240	0.796	0.012	0.061	<0.001
Flesh	Marion	0.988	0.059	0.185	1.967	0.074	0.098	0.018	40.250	8.750	5.750	28.250	4.000
	Lake	0.599	0.050	0.159	1.673	0.063	0.086	0.026	32.167	11.542	5.250	30.333	10.833
	P value	<0.001	0.293	<0.001	0.001	0.002	0.022	0.154	0.007	0.001	0.304	0.769	<0.001
Pit	Marion	0.604	0.054	0.078	0.414	0.083	0.247	0.042	12.375	0.042	11.292	241.958	10.495
	Lake	0.517	0.040	0.075	0.499	0.057	0.098	0.030	12.125	0.030	5.125	165.917	10.000
	P value	0.085	0.048	0.654	0.116	0.120	0.136	0.503	0.877	0.792	0.058	0.200	0.345

The nutrients nitrogen (N), sulfur (S), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na) are reported as a percent (%) of the total fruit. The nutrients boron (B), zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu) are reported as parts per million (ppm).

the unbagged control had a photochemical equilibration ratio of 1.04:1 (P_r:P_{fr}) with a fluence of 170 $\mu mol \cdot m^{-2} \cdot s^{-1}$. A lower P_r:P_{fr} ratio has been associated with the "shade-avoidance syndrome" with observed stem elongation (Ruberti et al., 2012). Given that fruit contain phytochrome, it is possible that a similar elongation to intercept unattenuated light may occur. The lack of diameter and fresh weight differences does not suggest that a different growth pattern (and corresponding tissue density) explains the firmness difference observed.

Liu et al. (2015) found that use of white polypropylene bags for 'Yulu' peaches resulted in higher anthocyanin concentration compared with unbagged fruit, as well as fruit bagged with blue polypropylene, gray polypropylene, black polypropylene, or yellow paper bags, and found that white and unbagged 'Hujingmilu' peaches had increased anthocyanin content relative to other colored bags. Their white polypropylene bag had a light transmittance of 90% at 300 nm with a gradual reduction to 75% at 750 nm. The white paper bags used for the present study allowed 50% *PAR* transmittance that followed the same spectral pattern as full sun, but the colored bag treatments permitted only a narrow range of wavelengths with lower transmission rates (*PAR* between 3.7% and 17.4%) compared with full sun. The protocol used by Zhang et al. (2015) was similar to the bag removal treatment in this experiment that did not expose the fruit to the sun until 7 DBH, and the findings support the direct association between light transmission rates and anthocyanin concentration. These combined results provide support that anthocyanin production in field bagging conditions requires full sunlight for maximum expression, may be directly related to incident *PAR*, and does not maintain or increase production in the presence of light restricted within specific spectral ranges. Photoreceptor activity for phytochrome B (Kretsch and Schäfer, 2000; Rausenberger et al., 2010), cryptochromes (Bouly et al., 2007; Procopio et al., 2016), and phototropins (Inoue et al., 2008) are fluence rate-dependent and more work is needed to determine if a sufficient quantity of light was being transmitted to elicit a response under these experimental conditions.

Nutrient assimilation. The lack of nutrient and compositional differences between peaches grown in a white paper bag vs. in full sun is a positive result for growers interested in maintaining peach fruit quality. The differences observed by location, which may be due to soil, meteorological conditions, or other management practices, show that peach nutrient concentration may be sensitive to these changes. Although Cu was significantly elevated in the fruit peel and flesh in Lake County, the opposite was observed in the leaves (data not shown but will be available online at the UF dissertation repository in 2023). Leaf samples collected in Lake County had Cu in the sufficiency range (5–16 ppm; Johnson, 2008) with a value of 6.5 ppm Cu as compared with 2 ppm Cu in Marion County. Before conversion to a peach orchards, the past land uses in Marion and Lake Counties were pasture and citrus production, respectively. According to our farmer collaborator, the prevalence of Cu-based agricultural sprays resulted in the elevated soil Cu concentration of 23.3 $mg \cdot kg^{-1}$ observed at the Lake County location as compared with reduced Cu sprays and reduced soil Cu concentration of 0.2 $mg \cdot kg^{-1}$ at the Marion County location. The increased soil Cu concentration might explain the correlation with fruit Cu concentration, but the in-tree fruit and vegetative allocation of Cu deserves further exploration.

Conclusion

The overall lack of fruit quality differences when growing peaches in bags is promising when considering the pest and disease management benefits, but more research is needed to determine if fruit quality can be enhanced with different-colored bags. Minimum fluence rates to ensure photoreceptor activity and elicitation of a response for field-grown peaches is needed. Additional questions that would further this research area include the following: Does light wavelength influence *M. fructicola* or other biological growth and potential infection rate (Yu and Lee, 2013)? Does light wavelength influence fruit volatile production that may attract arthropod pest activity or enhance fruit flavor? How do the interacting elements of temperature, RH, and light quality influence the photosynthetic capacity, downstream biochemical reactions, and stomatal conductance of peach fruit? As bagging research matures, we believe ideal materials and methods will become evident, and researchers along with industry would benefit from using standardized protocols and bagging materials to compare results among regions, crops, and pest/disease complexes.

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