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Colored Shade Nets Affect Growth but Not Flowering of Four Greenhouse-grown Potted Ornamental Species

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Abstract. **The color of horticultural shade nets is known to influence crop growth and quality because of variations in the amount and quality of light. Four ornamental plant species (celosia, begonia, gerbera, and fountain grass) were grown under aluminet, pearl, and red shade nets plus black as the control at 50% shade intensity for 8 weeks. Black had the least transmittance (~10% to 30% of ambient) within the red spectrum (620–750 nm), whereas red had the greatest at ~70% to 80%. Aluminet and pearl resulted in a similar reduction in photosynthetic photon flux at ~50% to 55% and ~55% to 65% of ambient, respectively. Aluminet increased the shoot dry weight for begonia and celosia, whereas no differences among shade nets were seen for gerbera or fountain grass. The chlorophyll concentration was greatest under aluminet for each species except begonia. Shade net color did not affect flower number.**

Colored shade nets are a common technology that can help alter the light spectrum and provide optimum light conditions for plant growth (Shahak et al. 2008). These shade nets are used to reduce light intensity and routinely scatter incoming light by up to 50% (Díaz-Pérez et al. 2020; Stamps 2009). Shade net effects are varied according to the crops and environmental conditions in which a crop is grown. During a study by Stamps and Chandler (2008), cast iron plant (*Aspidistra elatior* L.) performed best under black shade, whereas Japanese pittosporum (*Pittosporum tobira* T.) performed best under red shade. Hernandez et al. (2020) found that lisianthus (*Eustoma grandiflorum* D.) had longer stems with greater diameters under red shade, whereas leaf area was highest under blue shade. Similarly, Gaurav (2014) found that corn plants (*Draceana fragrans* L.) performed best under red shade for various growth parameters; however, ti plant (*Cordyline fruticose* L.) performed best under white shade. Responses to colored shade nets appear to be species-dependent. Thus, the objective of this study was to identify the optimal shade nets colors for plant growth and flowering of four common potted ornamental crops grown in a greenhouse during the summer in Oklahoma.

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Materials and Methods

An experiment was conducted at the research greenhouse facility at Oklahoma State University, Stillwater, OK, USA. No supplemental light was used in the greenhouse, resulting in daily light integral (DLI) levels of 17.2 ± 2.1 $mol \cdot m^{-2} \cdot d^{-1}$. Air temperature was set at 21/18 °C, resulting in an average of 30.5 ± 1.2 °C. Plugs of celosia ‘Fresh Look Orange’ (*Celosia cristata* L.), begonia ‘Olympia Red’ (*Begonia tuberhybrida* L.), fountain grass (*Pennisteum alopecurold* L.), and gerbera ‘Jaguar White’ (*Gerbera jamesonii* H.) were obtained from Ball Horticulture (West Chicago, IL, USA) in 288 cell trays. Celosia, fountain grass, begonia, and gerbera plugs were received on 13 May 2021, and transplanted on 17 May 2021, into 15-cm pots with a volume of 2650 cm^3 and filled with medium (BM-7, 45% bark; Berger, Sulfur Late Springs, TX, USA). Spacing of 30 cm between pots was applied. Polyvinyl chloride pipes with a diameter of 2.5 cm were used to make frames with a height of 0.762 m to hold the shade nets above the canopy. Shade net treatments included red, aluminet, pearl, and black (control) shade nets (Green-Tek, Janesville, WI, USA), with each having 50% shade with varying light transmittance depending on the shade net color (Fig. 1). Spacing of 1 m was applied between each shade net treatment. Water was provided to plants when required once per day with drip irrigation pressure compensating emitters at 7.8 L/h and a 15% leaching fraction. A 15N–3.9P–10.4K (5–6 months) slow-release fertilizer (Osmocote Plus, Dublin, OH, USA) was applied as a top-dress at 11.5 g per pot once at the time of transplanting.

Data of celosia and begonia, which were harvested on 28 Jun 2021, were collected 6 weeks after transplanting. Fountain grass and gerbera were harvested after 8 weeks on 12 Jul 2021. Measurements of plant height (from top of the pot), flower number, fresh weight, and dry weight were conducted at harvest from all plants. For dry weights, plants were oven-dried for 2 d at 53.9 °C. The chlorophyll content was measured using a chlorophyll meter (Minolta SPAD-502; Spectrum Technologies, Aurora, IL, USA) and recorded as the average of three points (upper, middle, and basal) on three leaves per plant. Net photosynthesis was measured between 12:00 PM and 3:00 PM using a LI-COR 6400XT (LI-COR Biosciences, Lincoln, NE) at a light intensity of 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on a single leaf taken from the middle of the plant. Transmittance was measured 2 weeks after transplanting during the middle of the day using a HL-2000-FHSA spectrometer (Ocean Optics, Shanghai, China). Photosynthetic photon flux, air temperature, and humidity were recorded using a datalogger installed under each shade net at pot level (Illuminance ultraviolet recorder TR-74Ui T&D; Matsumoto, Japan).

The experiment had a randomized complete block design comprising two blocks and 10 plants per treatment. The experimental units were single plants per cultivar per treatment. For measurements at harvest, a mixed-model method (SAS version 9.4; SAS Institute Inc., Cary, NC, USA) was used to account for unequal variance among treatment levels. Means were separated using Tukey’s method, and all tests were conducted at a significance level of 0.05.

Results and Discussion

There were significant differences among shade nets for DLI, air temperature, and relative humidity (data not shown). Pearl showed the greatest DLI (22.7 $mol \cdot m^{-2} \cdot d^{-1}$), which was different from that of aluminet, red, and black (18.5, 15.3, and 12.4 $mol \cdot m^{-2} \cdot d^{-1}$, respectively). The DLI of the pearl shade net was greater because of the reflective properties. Gaurav et al. (2016) found that the DLI was greater under white shade than under red or black shade. Similarly, Meena et al. (2014) found that the photosynthetic photon flux was greatest under pearl shade than under red, green, or black shade. Air temperature was greatest under red shade and lowest under aluminet shade at 31.3 °C and 29.7 °C, respectively. Austerman et al. (2023) also found the greatest temperature under red shade nets for pansy (*Viola wittrockiana* Gams). The relative humidity was greatest under aluminet (64.9%) and black (63.8%) shade and lowest under red (61.2%) shade. Black shade resulted in minimal blue light (∼25% of ambient) and red light (∼15% to 20%), but moderate yellow and green light (40%) (Fig. 1). Pearl shade resulted in transmittance ranging from 55% to 65% of photosynthetic photon flux, whereas aluminet resulted in ∼50% to 55%. Red shade transmitted ∼35% of ambient blue, green, and yellow light, whereas red light transmitted 70% to 80% of ambient.

The plant response varied depending on the species and shade net color (Table 1). Crowley (2007) also found that snapdragon (*Antirrhinum*

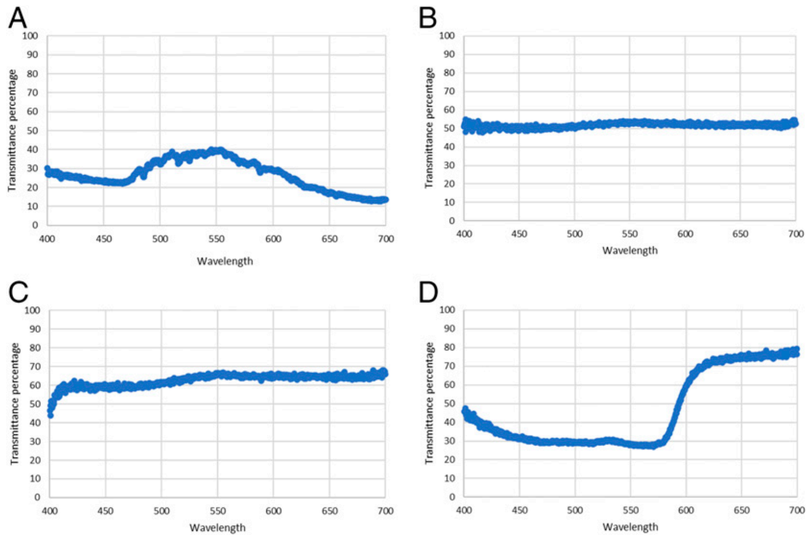

Fig. 1. Transmittance spectra between 400 and 700 nm under 50% black (**A**), aluminet (**B**), pearl (**C**), and red (**D**) shade nets within a single-layer polycarbonate greenhouse covering in Stillwater, OK, USA, in 2021.

Table 1. Main effects of treatment on shoot fresh weight, shoot dry weight, plant height, net photosynthesis, and chlorophyll concentration of celosia 'Fresh Look Orange', begonia 'Olympia Red', fountain grass, and gerbera 'Jaguar White' grown under aluminet, black, pearl, and red shade nets in Stillwater, OK, USA, during Summer 2021.

Species	Treatment	Shoot dry wt (g)	Plant ht (cm)	Net photosynthesis ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Chlorophyll concn (unitless)
Begonia	Black	9.6 b[i]	19.0 a	12.4 b	33.1 b
	Aluminet	10.7 a	19.8 a	18.9 a	36.5 a
	Pearl	9.9 ab	17.7 a	19.2 a	37.8 a
	Red	10.1 ab	20.0 a	20.1 a	32.5 b
Celosia	Black	11.2 b	28.0 a	10.3 c	35.7 b
	Aluminet	13.6 a	25.4 a	22.3 a	38.1 a
	Pearl	11.3 ab	26.0 a	20.2 b	35.4 b
	Red	11.1 b	26.0 a	20.8 ab	34.3 b
Gerbera	Black	11.1 a	22.8 a	22.3 ab	42.5 ab
	Aluminet	12.6 a	21.8 a	23.2 ab	44.9 a
	Pearl	13.0 a	20.7 a	23.8 a	40.9 b
	Red	11.7 a	21.6 a	20.3 b	39.5 b
Fountain grass	Black	10.6 a	111.1 a	24.1 a	43.5 a
	Aluminet	16.2 a	92.1 b	23.3 a	44.5 a
	Pearl	14.0 a	92.4 b	23.6 a	38.3 b
	Red	15.1 a	107.6 a	21.9 a	41.1 ab

[i] Means (n = 10) within a column followed by the same lowercase letter are not significantly different according to the pairwise comparison in the mixed model ($P \leq 0.05$).

majus L.), pansy, and celosia (*Celosia agrentia* L.) varied in their responses to colored plastic films. Celosia showed the greatest dry weight under blue film, whereas plant height was greatest under red film. The shoot dry weight showed significant treatment main effects for begonia ($P < 0.013$) and celosia ($P < 0.018$). Aluminet shade increased the shoot dry weight for begonia compared with black shade and for celosia compared with black or red shade. Similarly, Rupasinghe et al. (2015) found that aluminet shade increased rose (*Rosa hybrida* L.) yield more than black shade. Plant height only showed a significant main effect for fountain grass ($P < 0.001$). Black shade increased the plant height of fountain grass more than pearl and aluminet shade. Ovadia et al. (2015) similarly found increased stem length for cut flower species under red shade. Flowering was unaffected by the shade net color (data not shown). Austerman et al. (2023) also found that flowering of pansy was unaffected under different net colors.

Net photosynthesis showed significant main effects for begonia ($P < 0.001$), celosia ($P < 0.001$), and gerbera ($P < 0.04$). Net photosynthesis for begonia and celosia was less under black shade than under other shade colors, whereas red shade reduced net photosynthesis compared with pearl shade for gerbera (Table 1). Net photosynthesis for fountain grass was unaffected by the shade color. The chlorophyll concentration showed significant treatment main effects for begonia ($P < 0.002$), celosia ($P < 0.001$), gerbera ($P < 0.001$), and fountain grass ($P < 0.001$). The chlorophyll concentration was greatest under pearl, which was similar to that of aluminet, for begonia, whereas aluminet resulted in a greater chlorophyll concentration compared with pearl for the other species. Counce (2021) similarly found that the chlorophyll concentration was greatest under pearl and aluminet shade for hydroponically grown lettuce (*Lactuca sativa* L.).

Conclusion

The shade net color effects on growth parameters varied among species. Aluminet is recommended over traditional black shade nets for begonia and celosia based on the shoot dry weight. Black and red shade nets increased the plant height of fountain grass only, presumably because of insufficient DLI. Future studies should evaluate other shade net percentages, geographic locations, and time of year in relation to light and temperature level interactions with plant growth.

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