Height Control of Greenhouse-grown Pansy Using Colored Shade Nets

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Abstract. **Pansy (*Viola ×wittrockiana*) is a greenhouse crop commonly grown under black shade net; it often requires the use of chemical plant growth regulators to maintain a compact growth habit. Nonchemical efforts to alter plant morphology, such as height, would provide a more sustainable solution than chemical application. The objective of these studies was to evaluate the effects of different colors of shade nets on controlling growth and flowering of pansy. In Expt. 1, 'Clear Yellow', 'Buttered Popcorn', and 'Deep Orange' pansy plugs were placed under 30% blue or black shade net or, as a control group, where grown with no shade net. In Expt. 2, the same three cultivars of pansy were grown under 50% black, red, pearl, or aluminized shade net. Data were collected on plant height, plant width, flower number, plant survival, soil plant analysis development chlorophyll meter (SPAD) readings, and light quality. In Expt. 1, the blue shade net reduced height to flower and height to leaves, but also decreased flower number and plant survival as compared with black shade net. All plants under no shade died. In Expt. 2, SPAD, an indicator of plant quality by estimating leaf greenness, was found to be lower under black shade net, whereas pearl shade net led to a decrease in plant height and no effect on the number of flowers. Light quality, including red-to-far-red ratio, varied among shade treatments, whereas light intensity was reduced under aluminized, black (50%), and red shade nets compared with other shade treatments. Blue and pearl shade nets both reduced plant height, but blue shade net also reduced plant survival and flowering.**

Pansy (*Viola ×wittrockiana*) is one of the most popular annual bedding plants in the United States due to its being frost tolerant and ability to provide color in winter in warm climates or late fall and early spring in colder climates (Kessler and Behe 1998). Often in greenhouse production, pansy plants are grown from plugs in mid to late August to reach market size by late September or early October. In many parts of the United States, temperatures inside greenhouses can easily reach more than 38 °C during this time. However, pansy plants are best produced at temperatures below 18 °C, as multiple cultivars have shown a decrease in growth and flowering as temperatures increase (Carlson 1990; Niu et al. 2000; Warner and Erwin, 2006). Thus, pansy plants are often grown under black shade net ranging from 50% to 80% shading (Collado and Hernández 2022). The use of plant growth regulators (PGRs) in pansy production is also common to reduce stretching under the lower light levels (Collado and Hernández 2022; Kessler and Behe 1998).

Shade nets reduce air and canopy temperatures by physically blocking solar radiation including photosynthetic active radiation (PAR) around the crops and thus lowering thermal energy exchange (Stamps 2009). Díaz-Pérez and John (2019) reported colored shades improved growth of bell pepper (*Capsicum annum*) primarily because of reduced leaf and root zone temperatures under shaded conditions. Ilić et al. (2018) found that photoselective shade nets can be used to increase the postharvest quality of vegetables and can protect crops from excess environmental conditions.

Shade nets can be used outside over the top of greenhouses to reduce whole-house radiation load, as well as inside greenhouses to create targeted shade leading to a suitable environment for crop growth in hot and sunny regions (Ahemd et al. 2016; Arthurs et al. 2013). Traditional black shade net is made from woven opaque high-density polyethylene plastic with shading percentages typically ranging from 30% to 70% shade (Shahak and Gussakovsky 2004). These black shade nets serve only to provide shade proportional to their porosity and do not modify the spectral quality of radiation (Castellano et al. 2008).

Recently, several companies have begun to produce shade nets in an array of colors. These colored nets are designed to manipulate plant development and growth physiology by affecting light quality via light spectrum modification upon filtering through the net (Stamps 2009). Colored shade nets have been reported to have the ability to modify ultraviolet light, visible light, or red-to-far red (R:FR) light ratios based on the colors of the netting and that light fraction hitting the colored threads becomes spectrally modified and scattered, while the light passing through the holes of the net remains unmodified in spectrum (Shahak and Gussakovsky 2004).

Arthurs et al. (2013) found no significant alterations in R:FR light ratios under red, blue, pearl, and black shade nets as compared with ambient light, but blue shade net had consistently lower R:FR light ratio of all the nets. Blue shade net has been found

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
6.4516	$inch^2$	cm^2	0.1550
1	ppm	$mg \cdot L^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

to decrease length of ornamental foliage branches while increasing leaf variegation, as well as decrease stem length and flower size of sunflower (*Helianthus annuus*) and lisianthus (*Eustoma* sp.) (Oren-Shamir et al. 2001; Ovadia et al. 2009). Nissim-Levi and Lilach (2008) found that myrtle (*Myrtus communis*) and waxflower (*Crowea* sp.) flowering shrubs grown under pearl shade net exhibited more compact growth habit with more branches comparable to that achieved when using a chemical PGR, as well as a greater number of flowers per plant, compared with those under black shade net. The purpose of the present study was to evaluate the effects of different colors of shade nets for height control of pansy.

Materials and methods

Location and greenhouse conditions. The research was conducted in two greenhouses at the Research Greenhouse facility at Oklahoma State University, Stillwater, OK, USA (lat. 36°08'09.9″N, long. 97°05'10.9″W). No supplemental light was used in the greenhouse. Illuminance, temperature, and relative humidity were recorded with a datalogger (TR-74Ui; T&D Corp., Matsumoto, Japan). Daily light integral levels (DLI) ranged from 17.5 ± 5.2 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. The greenhouse temperatures were set 27 ± 6 °C (day) and 24 ± 2 °C (night).

Plant material and treatments. Seedlings of three pansy cultivars (Delta Premium™ Buttered Popcorn, Majestic Giants II Clear Yellow, and Matrix Deep Orange) were obtained from Ball Horticulture (West Chicago, IL, USA) in 288 cell trays with cells 3/4 inch × 3/4 inch × 1 1/2 inches deep. The plants were received on 19 Aug 2021 and were potted on 23 Aug 2021. Pansy plugs were individually transplanted into 1801 cell trays with cell 3 inches × 3 inches × 2 1/3 inches deep filled with growing media (BM-7 45% bark; Berger, Sulfur Springs, TX, USA). This media contains course grade peatmoss and perlite, bark, dolomitic and calcitic limestone, nonionic wetting agent, and a fertilizer starter charge. Trays were spaced ~1 ft apart. Polyvinyl chloride (PVC) pipes of 1-inch diameter were used to make a single frame, spaced 3.5 ft apart with no visual shading of other treatments, for each shade net treatment of 3-ft height to create a completely enclosed canopy around the trays. For Expt. 1, no shade, blue (ChromatiNet; Gothic Arch Greenhouses, Inc., Mobile, AL, USA) and black (Gothic Arch Greenhouses, Inc.) as the control at 30% shade nets was used. Expt. 2 was setup to look at other colors at 50% shading based on availability of a common shading percent among the different colors. For Expt. 2, treatments included red (ChromatiNet; Green-Tek, Inc., Clinton, WI, USA), pearl (ChromatiNet, Green-Tek, Inc.), aluminized (Aluminet, Green-Tek, Inc.), and black as the control. Plants were hand-watered throughout the experiment as needed with fertigation using a 15N–2.2P–12.5K water-soluble fertilizer (Jack's; JR Peter, Inc., Allentown, PA, USA) at a rate of 200 $mg{\cdot}L^{-1}$ was applied with each watering with 20% leaching fraction.

Data collection. Data were collected 6 weeks after transplanting for plant height to top of the highest flower, plant height to top of highest leaf, width (average of two perpendicular measurements), flower number (fully open), flower length, flower width, shoot dry weight (stems cut as soil level), soil plant analysis development (SPAD) chlorophyll meter (Minolta SPAD-502; Spectrum Technologies, Plainfield, IL, USA), leaf area (LI-3100C area meter; LI-COR Biosciences, Lincoln, NE, USA), plant quality, and plant survival for each treatment and experiment. For shoot dry weights, plant material was oven-dried for 2 d at 54 °C. SPAD readings were taken by scanning the middle of the two bottom-most leaves of each leaf to get a plant average. Leaf area was measured by selecting two mature leaves from the bottom of the plant and averaging the values (Karatassiou et al. 2015). Visual quality ratings (1 = green, active growth; 2 = some leaf browning and showing signs of stress; 3 = dying or dead) were taken. Plant survival was recorded as either alive or dead. Spectral data for light transmittance was measured 2 weeks after transplanting in the middle of the day using a spectrometer (model FLAME-S-VIS-NIR-ES; Ocean Optics, Orlando, FL, USA) with a range of 350 to 1000 nm.

Data analysis. Both experiments were arranged as a randomized complete block design with shade nets serving as the block and there were two replications. Each shade net had two replicates of 18 plants randomized per flat for Expt. 1 and two replicates of 12 plants in Expt. 2. In addition, each treatment had an environmental data logger. Data were analyzed from Expts. 1 and 2 separately using statistical software (SAS ver. 9.4; SAS Institute Inc., Cary, NC, USA). Percentages were calculated for plant survival among cultivars and shade net treatments. Tests of significance were reported at the 0.05, 0.01, and 0.001 levels. The data were analyzed using generalized linear mixed models methods. Tukey multiple comparison methods were used to separate the means.

Results and discussion

For Expt. 1, the no shade net treatment had the greatest DLI (19.5 $mol{\cdot}m^{-2}{\cdot}d^{-1}$) and temperature (26.8 °C) but the lowest relative humidity (54.5%) (Table 1). Gaurav (2014) also found that the no shade treatment had the greatest light intensity and temperature measurements compared with the shade net treatments. Mditshwa et al. (2019) noted that relative humidity is often significantly greater under shade netting. There was no difference between 30% black and blue for DLI, and according to Torres and Lopez

Table 1. Tests of effects for plant growth, flowering, quality, and survival of 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy cultivars grown under 30% black or blue colored shade nets along with no shade for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 1.

Shade treatment	Daily light integral ($mol{\cdot}m^{-2}{\cdot}d^{-1}$)	Temperature (°C)[i]	Relative humidity (%)
No shade	19.5 a[ii]	26.8 a	54.5 c
Black	6.8 b	25.0 b	59.5 a
Blue	7.5 b	25.6 ab	57.8 b

[i] (1.8 × °C) + 32 = °F.

[ii] Means followed by same letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

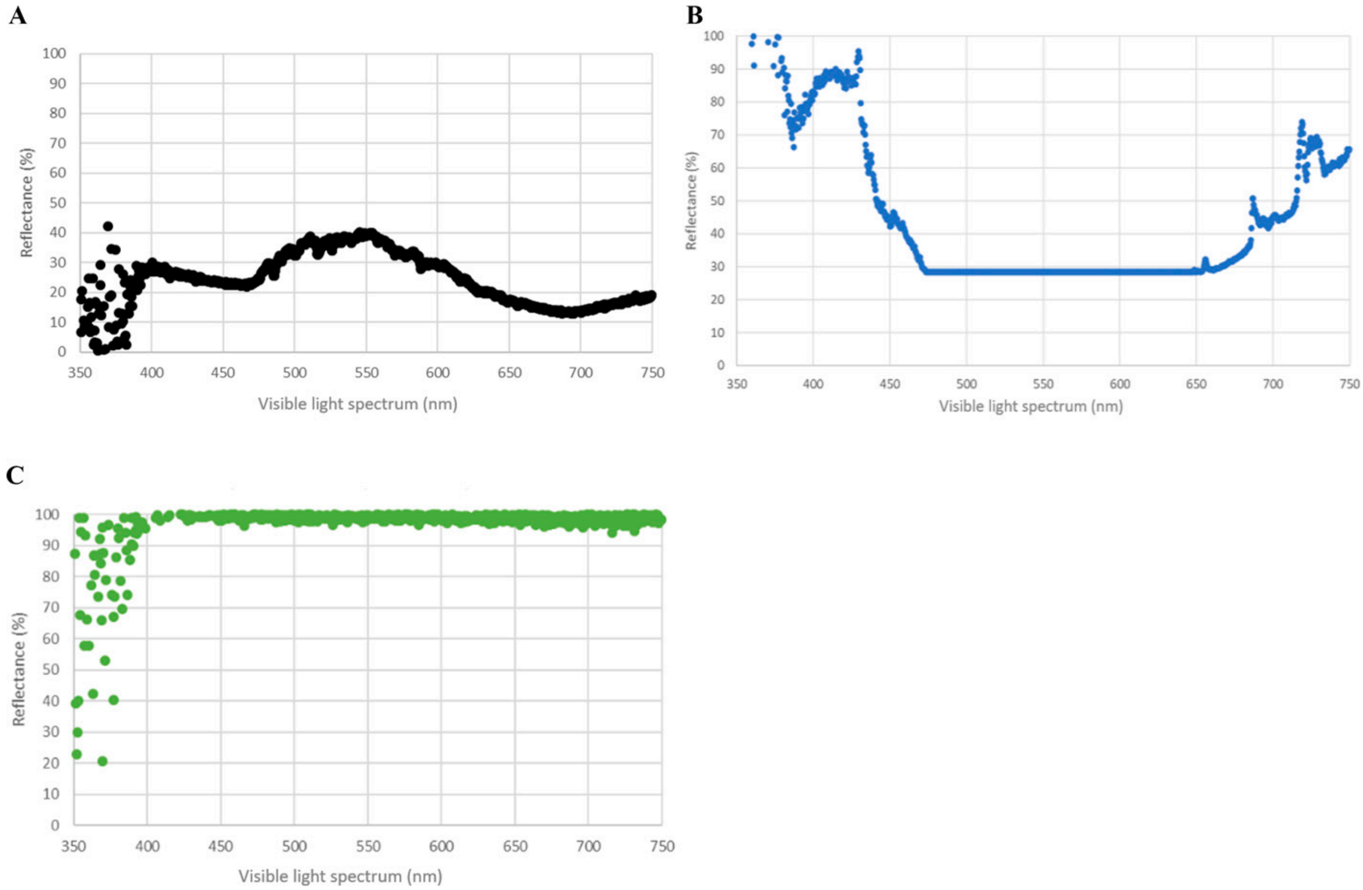

Fig. 1. Transmittance percentage of solar light under (A) black (30%) shade net, (B) blue (30%) shade net, and (C) no shade net. Percentages were measured using a spectrometer under each net in Stillwater, OK, USA, on a clear day in Sep 2021.

(2010), the values are within the minimum acceptable quality range for pansy.

Light spectral transmittance percentage was altered under black and blue shade nets compared with the no shade treatment (Fig. 1). Both shade nets were found to allow some ultraviolet A (UVA) radiation. In this study, black appeared to reduce transmittance the most. Among 30% shade nets, black transmitted ∼10% to 40% light in the PAR region of 400 to 700 nm and blue ∼30% to 80% with a peak of 400 to 425 nm, while no reduction was seen with no shade. Our findings were similar to Kotilainen et al. (2018), who also noted that blue nets have distinctive peaks between 450 and 495 nm and FR wavelengths beyond 750 nm. Blue shade nets had less than 1.0 R:FR ratios, defined as 660/730 nm according to Deitzer et al. (1979), whereas no shade nets were near 1.0. Arthurs et al. (2013) reported black nets gave R:FR ratios similar to ambient (R:FR ratio approaches 1.0), whereas blue nets lowered the R:FR ratio to around 0.8, and blue nets alter spectral quality more in the PAR/visible range. In our study, blue also had greater altered spectral quality in the PAR/visual range and the R:FR ratio was 0.6.

There was a significant shade × cultivar interaction for leaf area in Expt. 1 (Table 2). 'Clear Yellow' pansy had the greatest leaf area under blue shade net but was not different from any other treatment except 'Buttered Popcorn' under black shade net and 'Deep Orange' under blue shade net (Table 3). Leite et al. (2008) also found that blue shade net increased leaf area of moon orchid (*Phalaenopsis amabilis*). No significant

Table 2. Tests of effects for plant growth, flowering, quality, and survival of 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy cultivars grown under 50% colored shade nets (red, pearl, aluminized, and black) for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 1.

Variable	Shade	Cultivar	Shade × Cultivar
Plant height to flower	***[i]	NS	NS
Plant height to leaves	**	*	NS
Plant width	NS	NS	NS
Flower number	*	NS	NS
Flower length	NS	*	NS
Flower width	NS	*	NS
SPAD[ii]	NS	NS	NS
Leaf area	NS	NS	*
Dry weight	NS	NS	NS
Quality rating	NS	NS	NS
Plant survival	*	NS	NS

[i] Indicates significant at or nonsignificant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

[ii] Soil plant analysis development chlorophyll meter.

Table 3. Least squares means for the interaction of shade × cultivar for leaf area 6 weeks after growing three different pansy cultivars under 30% black or blue shade nets in Stillwater, OK, USA, in Fall 2021 for Expt. 1.

Shade treatment	Cultivar	Leaf area (cm^2)[i]
Black	Buttered Popcorn	2.0 b[ii]
Blue		2.2 ab
Black	Clear Yellow	2.1 ab
Blue		2.3 a
Black	Deep Orange	2.2 ab
Blue		2.0 b

[i] 1 cm^2 = 0.1550 $inch^2$.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \le 0.05$).

Table 4. Least squares means for treatment effects on plant height, flower number, and plant survival of 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy cultivars grown under 30% blue or black shade nets for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 1.

Shade treatment	Plant ht to flower (cm)[i]	Plant ht to leaves (cm)	Flowers (no.)	Plant survival (%)
Black	2.7a[ii]	2.3 a	0.9 a	71.6 a
Blue	2.5b	2.1 b	0.7 b	50.3 b

[i] 1 cm = 0.3937 inch.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \le 0.05$).

differences occurred between black or blue shade nets within a cultivar. Leaf area has been observed to increase in conditions of lower light intensity (Buisson and Lee 1993). Potter and Jones (1977) reported that plant relative growth rates were closely correlated with leaf area portioning in seven of the nine species studies. Weraduwage et al. (2015) noted that the relationship between leaf area growth and biomass depends on how carbon is partitioned among new leaf area, leaf weight, root weight, reproduction, and respiration.

There were significant treatment effects for height to flower, height to leaves, flower number, and plant survival (Table 2). Blue shade net resulted in lower height to flower, height to leaves, and flower number compared with black shade net (Table 4). Our findings support those of Oren-Shamir et al. (2001), where blue shade net caused a dwarfing effect in ornamental branches of Australian laurel (*Pittosporum variegatum*) compared with red and aluminized shade nets. This effect was also observed by Ovadia et al. (2009), where lisianthus and sunflower grown under blue shade net had decreased flower stem length compared with red shade net. This plant growth regulating effect was also seen with ground cherry (*Physalis* sp.) seedlings grown under blue shade net, which had more side shoots and less apical dominance than those grown under red shade net (da Silva et al. 2016). In that experiment, they hypothesized that this effect was due to the degradation of auxins via the light spectrum modifications resulting in an altered R:FR ratio. Specifically, phytochrome light receptors controls a suppressor (*SUR2*) gene and an enhancer (*TAA1*) gene of indole acetic acid biosynthesis under low R:FR ratios (Halliday et al. 2009). Kalaitzoglou et al. (2021) reported increasing the blue light fraction decreases growth mainly through its effect on plant morphology and light interception. Blue shade net resulting in decreased height to flower was contradicted by Nascimento et al. (2016), where blue shade net led to an increase in height to flower in sunflower compared with red but was not found to be significantly different.

None of the plants grown under no shade survived (Table 4), which may have been due to light intensity, temperature, or a combination of both. Overall quality of pansy plants has been shown to increase linearly as DLI increases up to a DLI of 26 $mol \cdot m^{-2} \cdot d^{-1}$, after which quality decreases if supplemental cooling is not added (Pramuk and Runkle 2005; Torres and Lopez 2009). Previous studies have shown similar quality decreases in pansy crops as temperatures increase across several cultivars (Torres and Lopez 2009; Warner and Erwin 2006). Pansy plants are ideally grown in daytime temperatures ~20 °C, with nights ~15.5 to 18 °C (Kessler and Behe 1998). Temperatures averaged ~27 °C for the no shade and would have exceed that temperature during the afternoon and when combined with greater DLI values may have also experienced greater water stress. Among shade treatments, blue shade net had a lower survival rate than black.

Significant cultivar effects were seen for height to leaves, flower length, and flower width (Table 2). 'Deep Orange' had the greatest height to leaves but was not different from 'Buttered Popcorn' (Table 5). 'Clear Yellow' had the greatest flower length and flower width but was not different from 'Buttered Popcorn'. A larger flower diameter than average is a known trait of the Majestic Giants II series of pansy; however, although the flower diameter was larger, the average plant height and width of the Majestic Giants II series was not significantly different from most other pansy cultivars (Kelly et al. 2005).

For Expt. 2, pearl shade net was greater than any other shade net for

Table 5. Least square means for cultivar effects on plant growth and flower effects of pansy cultivars grown under 30% black or blue shade nets for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 1.

Cultivar	Plant ht to leaves (cm)[i]	Flower length (cm)	Flower width (cm)
Buttered Popcorn	2.2 ab[ii]	1.6 a	1.5 ab
Clear Yellow	2.1 b	1.6 a	1.5 a
Deep Orange	2.2 a	1.4 b	1.3 b

[i] 1 cm = 0.3937 inch.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \le 0.05$).

Table 6. Environmental data including light intensity, temperature, and relative humidity of 50% aluminized, black, pearl, and red shade net treatments in Stillwater, OK, USA, during Fall 2021 for Expt. 1.

Shade treatment	Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)	Temperature (°C)[i]	Relative humidity (%)
Aluminized	4.7 b[ii]	24.3 b	65.8 a
Black	3.9 c	23.9 b	65.7 a
Pearl	7.9 a	25.3 a	63.6 b
Red	4.8 b	25.2 a	21.3 c

[i] (1.8 × °C) + 32 = °F.

[ii] Means followed by same letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

DLI (Table 6). Arthurs et al. (2013) found pearl nets were most effective at reducing the transmittance of both ultraviolet B (UVB) radiation (280–315 nm) and UVA radiation (315–400 nm), whereas red nets reduced transmittance of ultraviolet radiation the least. In this study, black appeared to reduce transmittance the most, whereas red shade net appeared to have slightly greater transmittance of UVA than pearl or aluminized (Fig. 2). Among the 50% shade treatments, black reduced PAR by ~90%, and aluminized was reduced ~60%, pearl ~80%, and red ~20% to 75%. Aluminized, pearl, and red shade nets had less than 1.0 R:FR ratios, whereas black 50% was near 1.0. Arthurs et al. (2013) reported pearl, black, and red nets gave R:FR ratios similar to ambient (R:FR ratio approaches 1.0); red nets alter spectral quality more in the PAR/visible range. In our study, red also had greater altered spectral quality in the PAR/visual range and the R:FR ratio was 0.6. Red shade net allowed ~25% to 40% transmittance from 450 to 575 nm then ~60% to 90% between 600 to 725 nm. These findings support Arthurs et al. (2013) who reported red nets allowed ~50% transmittance ~400 nm wavelength but produced more than 70% transmittance at wavelengths beyond 590 nm, and blue nets peaks in transmittance in the blue waveband (defined as 450 to 495 nm) and far-red wavelengths beyond 750 nm. Temperature was greatest under pearl but not different from red (Table 6). Relative humidity was greatest in aluminized and black (50%) shade net treatments at 65.8% and 65.7%, respectively, and lowest in red at 21.3% relative humidity. Low relative humidity in the red treatments may have been influenced by table drainage or malfunctioning sensors.

There was a significant shade × cultivar interaction for leaf area in Expt. 2 (Table 7). 'Buttered Popcorn' had the greatest leaf area when grown under pearl shade net but was only different from plants grown under black shade net (Table 8). 'Clear Yellow' had the greatest leaf area under the aluminized shade net but was not different

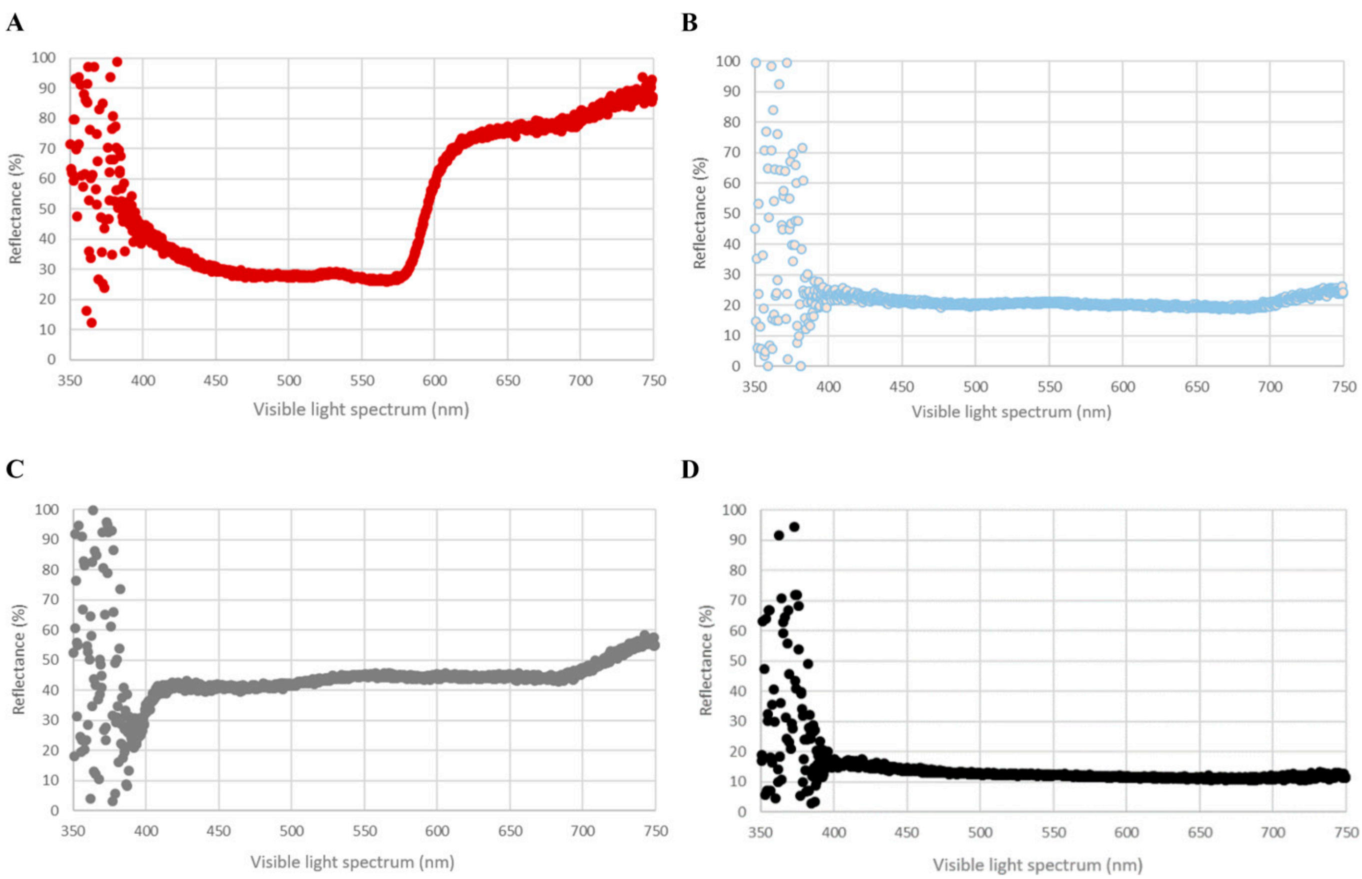

Fig. 2. Transmittance percentage of solar light under (A) red, (B) pearl, (C) aluminized, and (D) black shade net (all 50%). Percentages were measured using a spectrometer under each net in Stillwater, OK, USA, on a clear day in Sep 2021.

Table 7. Tests of effects for plant growth, flowering, quality, and survival of 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy cultivars grown under 50% colored shade nets (red, pearl, aluminized, and black) for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 2.

Variable	Shade	Cultivar	Shade × Cultivar
Plant height to flower	***[i]	NS	NS
Plant height to leaves	***	NS	NS
Plant width	NS	NS	NS
Flower number	NS	NS	NS
Flower length	NS	***	NS
Flower width	NS	***	NS
Leaf area	***	***	**
SPAD[ii]	**	**	NS
Dry weight	NS	NS	NS
Quality rating	NS	NS	NS
Plant survival	NS	**	NS

[i] Indicates significant at or nonsignificant (NS) at * $P \leq 0.05$, ** $P \leq 0.01$, or *** $P \leq 0.001$.
[ii] Soil plant analysis development chlorophyll meter.

Table 8. Least squares means for the interaction of shade × cultivar for leaf area 6 weeks after growing three pansy cultivars under 50% colored shade nets (red, pearl, aluminized, and black) in Stillwater, OK, USA, in Fall 2021 for Expt. 2.

Cultivar	Shade	Leaf area (cm^2)[i]
Buttered Popcorn	Red	2.3 bcd[ii]
	Pearl	2.5 abc
	Aluminized	2.5 abc
	Black	1.7 ef
Clear Yellow	Red	2.5 ab
	Pearl	2.4 bcd
	Aluminized	2.7 a
	Black	1.7 f
Deep Orange	Red	2.2 bcd
	Pearl	2.1 cde
	Aluminized	2.0 def
	Black	1.8 ef

[i] 1 cm^2 = 0.1550 $inch^2$.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

from the red shade net. 'Deep Orange' had the greatest leaf area under the red shade net but was only different from black shade net. Gaurav (2014) also found that red shade net increases leaf area, but in contrast to our findings, black shade net had the greatest leaf area.

In Expt. 2, there were significant treatment effects for height to flower, height to leaves, and SPAD (Table 7). Height to flower was greatest under red shade net but not significantly different from aluminized or black (Table 9). Height to leaves was also greatest under red but was not found to be significantly different from black. Zare et al. (2019) reported yellow increased plant height of violet (*Viola tricolor*) more than red or green at 50% intensity. Our findings support da Silva et al. (2016) in that red shade net resulted in the greatest stem length of several ground cherry seedlings but not being significantly different from black. The lack of significant differences between red and black treatments contradicts what Li et al. (2017) found with snapdragon (*Antirrhinum majus*) where red shade net resulted in significantly longer flower stems compared with black and blue shade net. This also contradicts the findings of Ovadia et al. (2009), who observed a significant increase in sunflower and lisianthus stem length under red shade net compared with black and blue shade net and Oren-Shamir et al.'s (2001) experiment growing Australian laurel in which red shade net resulted in the greatest overall stem length compared with black. The significant differences may be attributed to a species effect.

Pansy heights were lowest under pearl shade net, which is similar to results seen with Nissim-Levi and Lilach (2008), who found that myrtle plants grown under pearl shade net were shorter than those grown under black shade net by as much as 25%. The difference was attributed not to an alteration of light spectrum, but to a more even dispersal of light throughout the canopy of the plant, thus reducing the shade-avoidance effect seen when a plant is not getting enough light or only getting sunlight on the outside of the canopy. Kasperbauer and Wilkinson (1994) also reported that pearl shade net, whereas having a lower R:FR ratio may have had decreased plant height via scattering of light rather than direct alteration of the light spectrum as part of a decrease in plant shade-avoidance response. Shade avoidance is known to elicit plant elongation and greater biomass (Nissim-Levi and Lilach 2008). The shade-avoidance response is exacerbated by the spectrum of light changing as light passes through foliage toward the center of the plant, like the light scattered

Table 9. Least squares means for treatment effects for 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy plants grown under 50% red, pearl, aluminized, and black shade nets for 6 weeks in Stillwater, OK, USA in Fall 2021 for Expt. 2.

Shade treatment	Plant ht to flower (cm)[i]	Plant ht to leaves (cm)	SPAD (unitless)
Red	2.9 a[ii]	2.8 a	3.9 ab
Pearl	2.6 b	2.4 c	4.0 a
Aluminized	2.8 a	2.6 b	3.9 ab
Black	2.8 a	2.6 ab	3.8 b

[i] 1 cm = 0.3937 inch.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 10. Least square means for cultivar effects on 'Buttered Popcorn', 'Clear Yellow', and 'Deep Orange' pansy cultivars grown under 50% red, pearl, aluminized, and black shade nets for 6 weeks in Stillwater, OK, USA, in Fall 2021 for Expt. 2.

Cultivar	Flower length (cm)[i]	Flower width (cm)	SPAD (unitless)	Plant survival (%)
Buttered Popcorn	1.6 a[ii]	1.5 ab	3.9 ab	56.1 b
Clear Yellow	1.6 a	1.5 a	4.0 a	89.7 a
Deep Orange	1.4 b	1.3 b	3.9 b	97.3 a

[i] 1 cm = 0.3937 inch.
[ii] Means within a column followed by same letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

under pearl shade net, a less-altered spectrum of light can more evenly penetrate the inner parts of the plant (Nissim-Levi and Lilach, 2008).

SPAD was found to be lower under black shade net but not different from red or aluminized shade net (Table 9). Gaurav (2014) reported red shade net had a greater SPAD reading than black. This was attributed to increased PAR transmittance under red shade net compared with black, thus resulting in improved photosynthetic rate and chlorophyll content.

There was a significant cultivar effect for flower length, flower width, SPAD, and plant survival (Table 7). 'Clear Yellow' was the greatest for both flower length and width but was not different from 'Buttered Popcorn', which was consistent with what was seen in Expt. 1 under 30% black and blue shade net (Tables 5 and 10). In Expt. 2, plant survival was greatest for 'Deep Orange' and 'Clear Yellow', which indicates plant survival may have been influenced more by production practices like watering than from the shade nets (Table 10).

Conclusions

Blue and pearl shade nets both led to a decrease in plant height, but blue shade net also reduced plant survival and flowering, so pearl shade net showed the most overall potential for an alternative to chemical height control in pansy. Greater altered light spectral quality with greater amounts of blue light likely reduced plant growth. Pearl shade net had greater light intensity than red, aluminized, and black that could have resulted in reduced plant stretching. Light quality and quantity are known to affect plant growth (Oren-Shamir et al. 2001). In both experiments, black shade net resulted in cooler temperatures, but aluminized was not different from black at 50%, making them better for cooler season crops. Future research should evaluate different cultivars of pansy, shade net percentages, and direct comparisons of pearl shade net with chemical plant growth regulators as a potential sustainable alternative.

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