COLORED SHADE NETS EFFECT ON GROWTH, FLOWERING, AND CARBOHYDRATES OF VEGETABLE AND ORNAMENTAL PLANTS GROWN UNDER GREENHOUSE AND FIELD CONDITIONS

By

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Abstract: Light plays an important role in germination, phototropism, and reproduction. High light intensities can reduce plant quality and raise temperature above optimum in greenhouses. Photoselective colored nets can be used to modify and scatter incoming light radiation to provide varying light wavelengths and reduce temperature. In our experiment, four different colored shade nets (aluminet, black, pearl, and red) with 50% shading intensity along with no shade were used to study their effects on plant growth, quality, carbohydrate, and nutrient concentrations. Different vegetables and ornamental plants were selected and grown in a greenhouse and under field conditions (Bear Creek farm Stillwater and Wild Lark farm, Claremore). For lettuce (*Lactuca sativa* L.) and basil (*Ocimum basilicum* L.), no shade was greatest for biomass and chlorophyll concentrations, while aluminet and pearl shade nets resulted in the greatest sugar concentration and net photosynthesis rate. For celosia (*Celosia cristata* L.) and begonia (*Begonia tuberhybrida* L.) shoot dry weight were greatest under aluminet while gerbera (*Gerbera jamesonii* H.) and fountain grass (*Pennisteum alopecurold* L.) did not differ among shade net treatments. Flowering, among the four patted plant species was unaffected by shade net treatment. Plant height was greatest in red and black shade for fountain grass. Overall, plant response to different colored shade nets varies by species. However, aluminet increased sugars and nutrients of lettuce and basil and plant growth was increased under celosia, begonia, snapdragon, and dahlias in greenhouse. Red shade net would be recommended for increased flowering in dahlias and snapdragons under field conditions.

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CHAPTER I

LITERATURE REVIEW

Hydroponics

The world population is increasing and this increase in people and living standards has increased demand for fresh and high-quality produce, which results in a need for protected and soilless cultivation of crops (Raviv and Lieth, 2008). In countries having little agricultural land and vast populations, hydroponics is a means for production of fresh and healthy vegetables in greenhouses (Resh, 1987). Hydroponics is an ideal technology to mitigate production constraints like weeds, water availability, diseases, nutrients, and problematic soils for flower and vegetable production (Kumari et al., 2018). Hydroponics is derived from two Greek Words ‘Hydro’ means water and ‘Ponos’ means labor (Roberto, 2014). Hydroponics is a technique of growing plants without using any soil and by using water and liquid nutrients (Shrestha, 2010). Nutrient solutions are constantly available to the roots of plants which provide nutrition and aeration for plant growth and development. Plants grown in hydroponics are under less stress of water and nutrient requirements as compared to soil grown plants because plants are in direct contact with nutrients and are free from soil borne diseases and pathogens (Roberto, 2014). According to Sambo et al. (2019) hydroponics is a new technique that has potential to increase productivity and have an indisputable productive and environmental advantages due to greater water and nutrient use efficiency. AlShrouf (2017) also found that hydroponics provides a better alternative as compared to conventional farming to increase water and nutrient use efficiency. Nederhoff and Stanghellini (2010) found reduced water and fertilizer usage and minimal release of fertilizers and chemicals into the environment.

Light

The primary source of light on earth is sunlight, and every location on earth receives sunlight at least part of the year (Yavari et al., 2021). Both the quality and amount of incoming light can have a massive impact on photosynthetic activity and photosystem adaptation to changing light conditions (Givnish, 1988). Changes in light quality can alter various crop physiological and biochemical processes and metabolite qualities (Ilic et al., 2017). Light is the source of energy that regulates several growth and developmental processes such as photosynthesis and photomorphogenesis in plants (Teixeira, 2020).

Incident light on the earth's surface is a constantly changing and unstable element, necessitating development of plant adaption mechanisms (Belkov et al., 2019). The sun emits a continuous spectrum of energy between 250 to 2500 nm (known as the 'biological window') which affects living processes. Plants mainly use light between 400 to 700 nm (photosynthetically active radiation) for their growth and development, but various environmental factors can affect this incoming light spectrum (McCree, 1972).

Plants can adjust to changing light quality conditions and can sense light through a complex system of photoreceptors such as phytochromes (phy), cryptochromes (cry), and phototropins (phot) (Kotilainen et al., 2018; Ovadia et al., 2015). These photoreceptors also have the ability to sense intensity, direction, and duration of light (Frankhauser and Chaury, 1997). Phytochromes can respond to light in the visible spectrums red and far-red regions, while cryptochromes and phototropins are pigments that detects blue and ultraviolet (UV)-A wavelengths of light (Franklin et al., 2005). Chromophores in photoreceptors absorb light and converts these signals into biochemical signals that control plant processes (Kong and Okajiima, 2016).

Plant cryptochromes absorb light radiation ranging from UV-A to blue wavelengths and regulate plant growth and developmental processes (Frankhauser and Chaury, 1997). Cryptochromes are photoexcited after capturing light photons, with the use of flavin reduction and electron transfer mechanism cryptochromes make energy in different oxidation and reduction processes such as oxidized, semi reduced, and fully reduced (Wang et al., 2014). Phytochromes help to sense red and far-red light and regulate shade avoidance, germination, and de-etiolation in plants (Kong and Okaljiima, 2016). In dense plant communities, absorbance of red light and reflectance of far-red light resulted in an increased Red:Far-red (R:Fr) ratio reaching short plants, and increased R:Fr ratio induces inactivation of phytochromes and development of a shade avoidance response (Courbier and Pierik, 2019). Shade in plants escalates phytochrome interacting factor 5 (PIF 5) and PIF 4 and increases the production of auxin and depletion of della proteins and thus promotes stem elongation (Casal, 2012). Franklin and Whitelam (2005) also found that plants showed an increased stem elongation and petiole growth under shade due to changes in R:Fr ratio of light. Photosynthesis is the most important physiological process in which plants use light energy to produce carbohydrates. In photosynthesis, two photosystems which are present in chloroplast pigments works together and absorb a narrow range of light spectrum with the use of different photoreceptors (Teixeira, 2020).

Samuoliene et al. (2010) found that red colored light by light emitting diode (LED) lighting resulted in a 1.8 times greatest shoot/root ratio in frigo strawberries (*Fragaria ananassa* Duch.). He also found that combination of red and blue light helps to increase carbohydrate accumulation and chlorophyll pigment ratio. Similar results were found by Poudel et al. (2007) in grapes (*Vitis vinifera* L.), with increased shoot and internode length grown under red LED lights in the same study, and increased chlorophyll concentration grown under blue LED lights. Runkle and Heins (2001) found that blue light inhibits growth of flowering stems and adding far-red light to red light will help to increase growth and flowering in long day plants. Liu et al. (2015) found red light increased accumulation of anthocyanin in wild plants of arabidopsis (*Arabidopsis thaliana* L.) leaves.

Shade

Direct sunlight and high temperatures during the growing season have been reported to be detrimental to growth, reproductive development, and yield in plants with low light requirements (Ahemd et al., 2016). Light radiation is most crucial, which provides energy for photosynthesis, the basic manufacturing process in plants, several characteristics of plant structure, physiology, and allocation of resources altered with irradiation level (Ilic et al., 2017). Ahemd et al. (2016) found shading in a greenhouse helps to achieve optimum environmental conditions required for crop growth and development during summer. Shade not only affects the quantity of light received by plants, but other micro environmental conditions, such as temperature, humidity, and carbon dioxide (CO_2) levels (Hou et al., 2018). Austerman et al. (2022) in pansy (*Viola wittrockiana* Gams.) found that shade provided by colored shade nets helps to change light quality and R:Fr ratio under them. Aasamaa and Aphalo (2016) also found that vegetational shade and light reflectance from the plant canopy increases R:Fr ratio of light intensity which affects growth of plants. Plants cultivated with shade make more biomass with more developed roots than full sunlight, since shaded plants have expanded in height to get more light and very little resources are spent on roots (Pierson et al., 1990). Ilic et al. (2017) also found that plants grown under shade expand more under less light to get more light for photosynthesis and have larger leaf area. Growers have used shade nets to provide different level of shade to plants in greenhouses or in open field conditions based on light requirements or for cooling the greenhouse.

Colored shade nets

Every plant has different requirements of various climatic factors such as temperature, light, water, and nutrients. Light is the main factor that affects most of the plant processes, and every plant species has its own optimum light requirements under which that crop can give maximum productivity (Teixeira, 2020). Colored shade nets can disperse and reflect incoming light radiation and can screen different spectral components of solar radiation (Shahak et al., 2008). These nets are made of ultra-violet (UV) resistant plastic material and can also affect the microclimate of plants related to humidity, shade, and temperature and also protect plants from hail, insects, pests, wind, and storm damage (Stamps, 2009).

These nets are available in various colors such as black, blue, red, white, pearl, aluminet, yellow, green, and scarlet with different shade factors (20 to 90%) and can be used according to specification of the crops (Shahak et al., 2004). These nets can be mounted externally or internally in greenhouses and reduce intensity of solar radiation that is entering into greenhouse, thus making the environment in greenhouse more favorable for crop production (Hesham et al., 2016). These nets block some part of incoming radiation and diffuse the remaining radiation and scatter it completely over the whole crop canopy, thus radiation use efficiency of plants is increased (Shahak et al., 2008). Mditshwa et al. (2019) found that shade nets can reduce canopy temperature by 1.3 to 7.6%, light intensity by 9 to 46%, and relative humidity by 3.2 to 12.9% under them.

Effects of colored shade nets in vegetables

Mohawesh et al. (2022) found that shade nets helped to decrease temperature up to 5 to 10 °C in sweet pepper (*Capsicum annum* L.). They also found that pearl shade nets helped to increase shoot fresh and dry weight, while plant height and chlorophyll concentration was greatest under black shade nets. Ntsoane et al. (2016) observed that pearl nets with 40% shade intensity can improve ascorbic acid and myricetin in Ashbrook and anthocyanin content in Aquarell cultivars of lettuce

(*Lactuca sativa* L.). They also noted that all lettuce produced with pearl nets showed less weight loss and fruit quality after postharvest storage. In a review by Ilic et al. (2018), photoselective shade nets protected vegetables from various biotic and abiotic stresses and improved shelf life of vegetables by keeping them fresh for longer periods.

Counce (2021) found that colored shade nets help to modify incoming light radiation and affect growth, quality, and morphology of romaine lettuce. That study also found aluminet nets increase leaf area and total sugar content in lettuce leaves, while pearl nets increased total number of leaves and total soluble solid content in leaves. Ilic et al. (2015) showed that red colored nets in tomato (*Solanum lycopersicum* L.) improved lycopene content and leaf area index as compared to no shade and pearl colored nets helps to increase pericarp thickness in tomato fruits. In sweet pepper, Ilic et al. (2017) found that shade nets provide optimal conditions for plants growth and shade grown plants have increased total phenolic and chlorophyll concentration in plant leaves. He found that plants under blue and black colored nets had the greatest chlorophyll concentration and plants under red and pearl nets had increased total yield in pepper plants.

In a shade nets study on cucumbers (*Cucumis sativus* L.), Tafoya et al. (2018) also found that plants under red, pearl, and aluminet colored nets have better stomatal conductance and carbon dioxide (CO_2) assimilation rates. These nets also helped to increase yield and total number of fruits per plant. He observed that red nets with 30% shade intensity increased the leaf greenness by 22.8% and foliar area by 38.9% as compared to black colored nets and pearl nets increased leaf dry weight by 21.9% in comparison with black. The greatest yield increase of 71% was observed under pearl nets. Shahak et al. (2008) also found that red and pearl nets helped to increase productivity of bell pepper (*Capsicum annum* L.), leafy crops, and ornamental crops as compared to black and no shade.

Ilic et al. (2017) in lettuce found that shade affects production of chlorophyll a and b, carotenoid content, and composition of flavonoid contents in leaves. In the same study, plants grown under pearl and red shade had increased head weight, which was approximately 40% greater than unshaded plants. He also found that shade grown leaves had increased leaf area index and photosynthetic rate as compared to control. Pierson et al. (1990) and Diaz-Perez et al. (2020) also found that plants grown under shade had better effects on yield and quality of various crops as compared to crops grown without any shade.

Effects of colored shade nets in ornamental plants

Austerman et al. (2022) in a study on pansy found that shade nets helped in plant survival as all plants died that were grown without any shade nets. Black colored shade nets had maximum survival rate as compared to any other colored shade nets, while pearl and blue reduced plant height. Ovadia et al. (2015) found shade nets had a positive effect on stems and cut flower weight in lisianthus (*Eustoma grandiflorum* D.) and sunflower (*Helianthus annuus* L.). The authors also found that plants have longer branches and internodal length under red colored shade nets. In the same study, they found that blue colored nets reduce plant height and weight as compared to red, yellow, and pearl nets.

Yavari et al. (2021) found that red colored nets increase leaf area, chlorophyll concentration, and photosynthesis, while aluminet color nets reduced leaf area and biomass and did not have any effect on photosynthesis in arabidopsis leaves. Shahak et al. (2008) also found that shade nets affect various physiological and morphological processes of plants. They found that red and pearl nets had greater productivity of various ornamental and vegetable crops and reduced the attack of different insect pests up to 10-folds.

In a review by Stamps (2009), the author reported that colored nets influenced microclimatic properties such as temperature, radiation, air movement, photo selectivity, and relative humidity. The author also found increased vegetative growth, flowering, fruit quality, and yield in different vegetable and ornamental plants. Gaurav (2014) also found that shade nets increased plant biomass, height, leaf area and other growth parameters in cut greens. He found cordyline (*Cordyline fructiosa* L.) performed best under white shade nets and dracaena (*Draceana fragrans* L.) performed best with red shade nets.

Stamps and Chandler (2008) in a study on aspidistra (*Aspidistra elatior* L.) and pittosporum (*Pittosporum tobira* T.) species, showed that effects of shade nets vary according to crops and shade nets. He found aspidistra showed increased growth and yield under black nets. He also found that net color affects yield, growth, color, and chlorophyll concentration in pittosporum leaves. Hernandez et al. (2020) in lisianthus found that red shade nets help to increase stem height and diameter. While no shade had the greatest leaf area, internodes, and buds followed by no shade treatments and lowest under blue nets.

CHAPTER II

COLORED SHADE NETS IMPROVE GROWTH AND NUTRITION OF LETTUCE AND BASIL

Abstract

Colored shade nets are known to alter light quality and quantity and thus can influence plant growth and nutritional quality of crops. Two cultivars of lettuce (*Lactuca sativa* L.) (Lollo Antonet and Green Forest) and basil (*Ocimum basilicum* L.) (Aroma-2 and Genovese) were grown in ebb and flow hydroponic tables for 4 weeks. Colored shade nets of aluminet, black, pearl, and red with 50% shading intensity along with a control having no shade were used in this experiment. Data for various growth and quality parameters were collected at the time of harvesting. The no shade treatment showed increased shoot fresh weight, dry weight, sugar, and chlorophyll concentration in both lettuce and basil cultivars, while plant height and net photosynthesis rate were increased under aluminet, pearl, and red nets. In basil, calcium and sulfur were greatest under no shade while zinc and copper were greatest under aluminet. In lettuce zinc, iron, calcium, magnesium, and manganese were greatest under no shade. The pearl colored net increased leaf °Brix. Overall, plants under no shade with daily light integral of 20 to 24 $mol \cdot m^{-2} \cdot d^{-1}$ and temperature of 26 to 30 °C from performed best to increase quality and growth of lettuce and basil in late late spring and fall

as compared to different colored shade nets. Spectral quality showed 90% reflectance of light ranging from 400 to 700 nm under no shade, 65% under pearl, 50% under aluminet, 30% under

black, while under red shade 70% reflectance ranged from 600 to 700 nm and only 30% reflectance ranging from 400 to 600 nm.

Introduction

In areas having little arable land or poor distribution systems, hydroponics is a means for production of fresh and healthy vegetables in greenhouses (Resh, 1987). According to Roberto (2014), plants grown hydroponically grow very quick and are healthier because roots are directly in contact with nutrient solution and water. The advantages of hydroponics over soil production include the plants grow faster, plant fertility is very precise, and problems associated with poor soils can be avoided (Savvas and Passam, 2002). There are numerous crops that can be grown using hydroponics in greenhouses that have short production cycles including lettuce, basil, swiss chard (*Beta vulgaris* L.), kale (*Brassica oleracea* L.), and various Brassica family crops (Singh, 2017).

Lettuce is an herbaceous leafy vegetable and is grown worldwide for its importance in the daily human diet and nutrition (Mou, 2009). Lettuce is mainly consumed as a salad and is ranked second in terms of vegetable consumption in the United States (USDA, 2016). Lettuce is a cool season crop with optimum temperatures ranging from 15.5 to 18.3 °C for growth (Masarirambi et al., 2018). Lettuce contains vitamin C, polyphenols, and fibers which help to improve health, prevent nutrient deficiencies, and reduce cardiovascular diseases (Shatilov et al., 2019).

Basil is a tender herbaceous warm season plant that grows between 10 to 30°C and prefers high light conditions (Currey, 2020). It is a very popular crop and can be easily grown in controlled environmental conditions and hydroponic systems (Sipos et al., 2021). Basil consumption is increasing rapidly due to its aromatic compounds, phenolic concentrations, and rich flavors (Dou et al., 2018). Basil is commonly used as an herb in various cooking operations such as flavoring, food preservation, and provides some essential aromatic oils (Li and Chang, 2015).

From germination to maturity, plants respond physiologically and morphologically to environmental factors such as light, temperature, nutrient application, and humidity. Light is the major factor that attributes to growth and development in plants and controls various mechanisms such as photosynthesis and photomorphogenesis (Teixeira, 2020). According to McCree (1972) sunlight reaching the earth's surface has a vast spectral range (250 to 2500 nm), but only light between 400 and 700 nm is considered photosynthetically active radiation (PAR). Plants have developed various adaptation molecules to efficiently detect or absorb light; these as molecules include phytochromes, chlorophylls, carotenoids, and cryptochromes (Belkov et al., 2019). Every crop has an optimal requirement of light as low light can reduce the quality of a crop and too high light intensity will not increase productivity and can cause heat stress (Torres and Lopez, 2012).

Plants-based diets have been used by people having various degenerative diseases (Nicolle et al., 2004). Fruits and vegetables are important sources of micronutrients and vitamins critical to cellular function (Martin et al., 2002). Environmental factors such as temperature, light, and relative humidity are major concerns that can affect optimal productivity and nutritional quality of crops grown in both field and greenhouse conditions (Ntsoane et al., 2016). Light is an unstable environmental factor and is very hard to control (Belkov et al., 2019), but changes in light quality could possibly modify crop physiological and biochemical processes (Ilic et al., 2017). These alterations in turn affect quality and quantity of phytochemicals and nutrients in plant leaves. After light, temperature is the next major factor that controls growth and development in plants. High temperature due to intense solar radiation can cause various abiotic stresses in plants that deteriorate the quality of produce (Ilic et al., 2018). A new technique of colored shade nets has been developed to supply plants with spectrally modified light that enhances desirable traits in the crop.

Colored nets are made from photoselective materials and help to change the spectral composition of incident light (Shahak et al., 2008; Ganelevin, 2008). Colored shade nets are available in various colors such as red, black, pearl, yellow, blue, aluminet, and green with shading factor ranging from 5 to 90%. These shade nets can protect plants from wind, bird, hail damage, light intensity, and disperse light radiation up to 50% that is reaching the plant canopy (Stamps, 2009; Diaz-Perez et al., 2020). Colored shade nets are made to specifically screen different portions of light and transform incoming light radiation by absorbing, transmitting, or reflecting targeted bands of light (Shahak et al., 2008). This scattered light radiation has better light use efficiency in plants because of diffused component of light because diffused light can penetrate more in plant canopy. (Shahak et al., 2008). Ilic et al. (2017) found that microclimate modification using colored shade nets can help to increase yield and improve fruit quality in sweet pepper (*Capsicum annum* L.) plants. The objective of this study was to see which color shade net could improve nutrition, quality, and growth of two different cultivars of a cool season (lettuce) and warm season (basil) hydroponic crops in late spring and fall.

Materials and methods

Location and greenhouse conditions

The research was conducted at the research greenhouse facility at Oklahoma State University, Stillwater campus (36.1361,-97.0863). No supplemental light was used in the greenhouse, and the daily light integral (DLI) averaged 15.7 ± 2.9 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ PAR. The controller was set to 21/18 °C in the greenhouse resulting in a daily average temperature of 27.8 ± 1.6 °C.

Plant material and treatments

Lettuce (‘Lollo Antonet’ and ‘Green Forest’) and basil (‘Aroma-2’ and ‘Genovese’) were obtained from Johnny Selected Seeds (Winslow, ME) on 15 April 2021. Seeds were placed in Horticube foam cubes (Oasis Grower Solutions, Kent, OH) with one seed placed in each 1.90 cm × 2.22 cm × 3.81 cm size cube on 15 April 2021 and 27 August 2021. Trays were kept under mist for 3 weeks. Treatments included red, black, aluminet, and pearl-colored shade nets (Green-Tek, Janesville, Wisconsin) with 50% shade intensity plus a control of no shade. Seedlings were then transferred to ebb and flow tables (1.5 m × 1.8 m), which had a floating styrofoam sheet with 5 cm holes spaced at 27 cm between holes. Net pots (CZ Garden Supply, Amazon, Seattle, WA) with 5 cm diameter openings were used. Ecoplus fixed flow water pumps (Sunlight Supply, Vancouver, WA) with 396 gallons per hour pumping capacity were used to pump the water. Polyvinyl chloride (PVC) pipes of 2.5 cm diameter were used to make frames of 0.762 m in height to hold the colored shade nets that went along the top and sides. A 20N-8.6P-17.4K general-purpose water-soluble fertilizer (J.R Peters, Allentown, PA) was used. The electrical conductivity (EC) (1.5 to 2.0 $mS\cdot cm^{-1}$) and pH (5.5 to 6.5) were maintained using an EC/pH meter (HI9813-6, Hanna Instruments, Rhode Island). A pH modifier (pH Down, General hydroponics, Santa Rosa, CA) was used to lower the pH.

Data collection

All data were collected 4 weeks after transplanting seedlings into tables. Data were collected on the shoot and root fresh weight, shoot and root dry weight, plant height, chlorophyll concentration, and photosynthesis rate. Plant material was oven-dried for 2 d at 53.9 °C for dry weights. Chlorophyll measurements were made using a chlorophyll meter (Minolta SPAD 502, Spectrum Technologies, IL), data was collected from one upper, middle, and base leaf by inserting a middle portion of the leaf in the sensor. Net photosynthesis rate was measured using a (Li-Cor 6400, Li-Cor Biosciences Lincoln, NE) at a light intensity of 1000 $\mu mol\cdot m^{-2}\cdot s^{-1}$ PAR. Spectral data for transmittance was measured after 2 weeks of transplanting near solar noon using a spectrometer (HL-2000 FHSA, Ocean Optics, Shangai, China). Illuminance, temperature, and humidity were recorded with an Illuminance UV recorder TR-74Ui (T&D, Matsumoto, Japan).

Nutrient analysis

After 4 weeks of transplanting, three plants per treatments dried and dried leaf samples were submitted to the Soil, Water, and Forage Analytical Laboratory (SWAFL), at Oklahoma State University, (Stillwater, OK) for nutrient analysis. Inductively coupled plasma mass spectrometry

(Thermo Fisher Scientific Waltham, MA, USA) was used to analyze samples for most nutrients. An elemental analyzer (836 series, LECO Europe, Geleen, Netherlands) was used to analyze nitrogen.

Carbohydrate analysis

Six leaves of basil from top, middle, and bottom part of plant or one central leaf of lettuce were collected as sub-samples and dried as previously described. The dried sub-samples were ground into powder using a grinder (Mini-Bead Beater 96, Biospec Products, Bartlesville, OK). Subsequently, 25 mg of the powdered sample was analyzed for carbohydrate concertation using the anthrone reagent method in which samples were dehydrated and depolymerized by concentrated sulfuric acid (H_2SO_4) to form furfural or hydroxymethyl furfural. The active form of the reagent is anthronol, the enol tautomer of anthrone, which reacts with the carbohydrate furfural derivative to give a color that is either green in diluted solutions or blue in concentrated solutions. This color may be seen by measuring the absorbance at 620 nm. After being incubated in 1 mL of ultra-pure (UP) water at 70 °C for 15 minutes, fine powder samples (25 to 27 mg) were centrifuged for 10 minutes at 15000 rpm. Anthrone was used as a reagent to measure the amount of soluble sugars in the supernatant after diluted with UP water (1:20 v/v). The remaining pellet was cleaned with water and 95% ethanol (v/v) before being heated to 100 °C for 10 minutes to allow starch to gelatinize. After that, it was digested for 4 hours at 37 °C using amylo-glucosidase (700 units/ml), alpha-amylase (70 units/ml), and sodium acetate (0.2M, pH 5.5) in a Roto-Therm™ Plus Incubated Rot (H2024, Benchmark Scientific, USA). Following incubation, samples were centrifuged at 15000 rpm for 5 minutes. The supernatant was utilized for measurement after being diluted with UP water (1:4 v/v) (Kaur, 2021). A microplate reader (Epoch, Biotek Instruments Inc. Winooski, VT) was used to read sample plates at 620 nm wavelength, which gives sugar and starch content in leaves. °Brix was also measured using a handheld refractometer (Fjdynamics, Chinatown, Singapore) in which a single leaf was taken from the middle portion of a plant.

Data analysis

This experiment was arranged in a randomized complete block design with two replications at the same time. There were five treatments, and the experiment was repeated over late spring and fall. The experimental unit was nine plants per cultivar of each crop. Data analysis was done by using SAS 9.4 (SAS Institute, Cary, NC). Tests of significance were reported at the 0.05, 0.01, and 0.001 levels. The data was analyzed using generalized linear mixed model methods. Tukey multiple comparison methods were used to separate the means. Proc corr method in SAS 9.4 was used to check correlation between carbohydrates and °Brix among season and cultivars combining shade treatments of both lettuce and basil.

RESULTS

Light intensity and quality, temperature, and relative humidity

There were significant differences between shade nets for DLI, temperature, and relative humidity during the late spring and fall seasons (Table 2.1). During late spring and fall, no shade showed the greatest DLI. Temperature during late spring was greatest under red. In the fall, temperature was greatest in no shade, which was not different from pearl and red treatments. During late spring, relative humidity was greatest under aluminet which was not different from black. In fall, relative humidity was greatest under aluminet. Aluminet and pearl showed light ranging from blue to red spectrum of light under them, similar to no shade but the reflection percentage was different between all (Figure 2.1). No shade had 90 to 100% reflection percentage while in aluminet reflection was 55 to 65% and in pearl between 50 to 55%. Black shade showed 35% reflection of blue light and nearly 50% reflection of green to red light. Under red shade, red light showed reflection percentage of 70 to 80% while blue to green light reflection was only 30 to 40%.

Season × Cultivar × Treatment interaction in basil and lettuce for plant growth

In basil, plant height showed a significant three-way interaction between Season × Cultivar × Treatment (Table 2.2). In late spring, greatest plant height was seen in no shade which was only different from black and aluminet for 'Aroma-2' (Table 2.3). For 'Genovese' plant height was greatest for pearl, but there was no significant difference between any colored shade nets. During fall in 'Aroma-2', red showed greatest plant height which was only different from black. For 'Genovese' in fall, red showed greatest plant height which was different from aluminet, black, and pearl.

In lettuce, plant height and chlorophyll concentration showed significant three-way interaction between Season × Cultivar × Treatment (Table 2.2). For plant height both cultivars of lettuce did not show any difference under different shade treatments in the late spring (Table 2.3). In the fall, plant height under different treatments was not different for 'Lollo Antonet', while 'Green Forest' showed greatest plant height under red which was different from no shade and pearl. For both late spring and fall, chlorophyll concentration was not different for any cultivar or treatment, but there were differences among seasons and cultivars. Overall, fall season performed best as compared to late spring season under different shade nets in both cultivars of lettuce for chlorophyll concentration.

Cultivar × Treatment in lettuce and basil for plant growth

In basil, there was a significant interaction between Cultivar × Treatment for shoot dry weight, root fresh weight, and photosynthesis rate (Table 2.2). No shade showed greatest shoot dry weight and root fresh weight in both cultivars of basil (Table 2.4). Aluminet showed the greatest photosynthesis rate for both cultivars, however in 'Genovese' aluminet was only different from red.

In lettuce, shoot fresh and dry weight, root fresh weight, and photosynthesis rate showed significant interaction between Cultivar × Treatment in lettuce plants (Table 2.2). 'Lollo Antonet' showed greatest shoot fresh and dry weight in the no shade which was different from black and pearl (Table 2.4). In 'Green Forest' shoot fresh weight was greatest under aluminet, while shoot dry weight was greatest with no shade which was different from aluminet, black, and red. The no shade showed greatest root fresh weight, which was different than aluminet, black, and red in 'Lollo Antonet'. In 'Green Forest', root fresh weight was greatest in no shade. For 'Lollo Antonet' photosynthesis rate was greatest in aluminet which was different from no shade and red. In 'Green Forest' black showed greatest photosynthesis rate which was only different from red.

Season × Treatment in basil and lettuce for plant growth

Basil showed a significant interaction between Season × Treatment for shoot fresh and dry weight, photosynthesis rate, and chlorophyll concentration (Table 2.2). Shoot fresh weight and shoot dry weight was greatest for no shade during both seasons (Table 2.5). While photosynthesis rate was greatest in aluminet which was different from no shade and red in late spring. During fall, photosynthesis rate was greatest in aluminet but different from black, pearl, and red. In late spring, chlorophyll concentration did not show any significant differences among treatments, but during fall chlorophyll concentration was greatest with no shade which was only different from aluminet and red.

In lettuce, shoot fresh weight, shoot dry weight, and photosynthesis rate showed significant interaction between Season × Treatment (Table 2.2). Shoot fresh weight in late spring season was greatest in no shade, which was different than black, pearl, and red (Table 2.5). During fall, shoot fresh weight under aluminet was greatest which was different from black, no shade, and pearl. No shade showed greatest shoot dry weight in late spring which was different from than aluminet, black, and red. During fall, shoot dry weight was greatest in no shade which was different than black and pearl. In aluminet photosynthesis rate was greatest in late spring and fall which was not different than any other treatment except red.

Season × Cultivar in basil and lettuce for plant growth

Significant interaction for shoot fresh weight, and chlorophyll concentration was seen between Season × Cultivar in basil (Table 2.2). During late spring, ‘Genovese’ showed greatest shoot fresh weight while chlorophyll concentration did not show any differences among cultivars (Table 2.6). In fall, there was not any significant differences between cultivars for shoot fresh weight while chlorophyll concentration was greatest for ‘Aroma-2’ compared to ‘Genovese’. In lettuce, significant interaction between Season × Cultivar was seen for shoot fresh weight and shoot dry weight (Table 2.2). Shoot fresh and dry weight did not show any significant difference in both cultivars of lettuce during late spring season (Table 2.6), but in the fall ‘Lollo Antonet’ showed greater shoot fresh weight and shoot dry weight than ‘Green Forest’.

Treatment and cultivar main effect in basil for plant growth

Main effects of treatment and cultivar were significant for root dry weight in basil (Table 2.2). No shade had the greatest root dry weight (4.2 g) as compared to all other treatments in basil (data not shown). Root dry weight was significantly greater in ‘Genovese’ (3.0 g) than ‘Aroma-2’ (1.9 g) (data not shown).

Cultivar × Treatment interaction for lettuce and basil for nutrients

Basil plants showed Cultivar × Treatment interaction for potassium under different colored shade nets for both cultivars (Table 2.7). ‘Aroma-2’ showed the greatest potassium concentration under black treatment which was only different from aluminet treatment (Table 2.8). While ‘Genovese’ had greatest potassium concentration under red but was not significantly different than any other treatment.

In lettuce magnesium, iron, copper, and manganese showed significant interaction between Cultivar × Treatment for lettuce cultivars under different colored net treatments (Table 2.7). ‘Green Forest’ showed greatest concentration of magnesium and iron under the no shade treatment which was not different than pearl (Table 2.8). In ‘Lollo Antonet’ magnesium concentration was greatest under pearl treatment which was different than black treatment and iron concentration did not show any significant differences among different treatments. The no shade treatment showed the greatest copper concentrations in ‘Green Forest’ which were different than black and red treatments, while ‘Lollo Antonet’ showed greatest copper concentration under pearl treatment but not different from all other treatments. In ‘Lollo Antonet’ manganese concentration was greatest with no shade. ‘Green Forest’ under no shade showed the greatest concentration of manganese which was different from black and pearl treatment.

Cultivar main effects in basil and lettuce for nutrients

In basil main effects of cultivar were significant for phosphorous, calcium, boron, zinc, and manganese in both basil cultivars (Table 2.7). ‘Genovese’ had the greatest concentration of phosphorous, calcium, boron, zinc, and manganese as compared to ‘Aroma-2’ (Table 2.8). In lettuce, main effects of cultivar were significant for calcium, potassium, sulfur, and zinc (Table 2.7). ‘Lollo Antonet’ showed greatest concentrations of calcium, potassium, sulfur, and zinc as compared to ‘Green Forest’ (Table 2.9).

Treatment main effects in basil and lettuce for nutrients

Main effects of treatment in basil were significant for nitrogen, phosphorous, calcium, boron, zinc, copper, and manganese (Table 2.7). Black shade net showed greatest nitrogen concentration while aluminet showed greatest copper concentration (Table 2.10). Calcium showed the greatest concentration with the no shade which was different than pearl and black. Phosphorous and manganese concentration was greatest under black which was not different than aluminet and no shade treatment. Aluminet net showed the greatest concentration of boron, under which was not different than black treatment. Zinc concentration was greatest under aluminet treatment which was different than pearl treatment.

In lettuce, main effects of treatment were significant for nitrogen, phosphorous, calcium, potassium, sulfur, boron, and zinc under different treatments (Table 2.7). Nitrogen, sulfur, and boron concentrations were greatest under black treatment which were different than red (Table 2.10). Pearl showed the greatest phosphorous concentration which was not different than the no shade. Calcium concentration was greatest under no shade, while potassium concentration was greatest under pearl. No shade treatment showed the greatest zinc concentration which was only different than black treatment.

Season × Cultivar × Treatment interaction in basil and lettuce for carbohydrates

Both basil and lettuce showed a significant three-way interaction between Season × Cultivar × Treatment for sugars and starch (Table 2.11). For basil during late spring, 'Aroma-2' showed greatest sugar concentration under aluminet, while 'Genovese' did not show any significant differences for sugars between different treatments (Table 2.12). In fall, sugar concentration in 'Aroma-2' was greatest under pearl, which was not different than the no shade, and in 'Genovese' sugar concentration was greatest under pearl treatment. Starch during late spring, was greatest with the no shade in 'Aroma-2' and in 'Genovese' starch was greatest under pearl which was different than aluminet and red treatments. In fall, starch in 'Aroma-2' did not show any significant differences among treatments, but in 'Genovese' starch was greatest with the no shade treatment which was not different than black and red treatments.

For lettuce during late spring, 'Lollo Antonet' showed greatest sugar concentration under aluminet which was not different from black (Table 2.12). 'Green Forest' showed greatest concentration of sugars under aluminet. In fall, there was not any significant differences for sugars among treatments in 'Lollo Antonet', while in 'Green Forest' sugar concentration was greatest with no shade which was not different than black. Starch during late spring, did not show any significant difference among treatments for both cultivars. In fall, 'Lollo Antonet' showed greatest concentration of starch under pearl while for 'Green Forest' starch concentration did not show any significant differences among treatments.

In basil, only main effects of treatment and cultivar were significant (Table 2.11). 'Aroma-2' showed greater °Brix values (4.3) as compared to 'Genovese' (4.0) (data not shown). Among colored treatments, pearl (4.4), aluminet (4.4), and no shade (4.3) were greater than red (4.1) and black (3.7). In lettuce, cultivar and treatment interaction and season main effects were significant for °Brix (Table 2.11). Aluminet treatment showed greatest °Brix values for 'Lollo Antonet' (2.8) and 'Green Forest' (3.5) cultivars of lettuce as compared to other treatments (data not shown). °Brix values were greater during late spring season (3.0) as compared to fall season (2.7). There was not any strong positive correlation between °Brix and sugars, or °Brix and starches, but during late spring basil cultivar 'Genovese' showed a slightly positive correlation between °Brix and sugars (Table 2.13).

Discussion

Environmental conditions

Shade nets reduced direct solar radiation reaching plants and maintained lower temperatures for both late spring and fall seasons. Among colored shade nets pearl shade had the greatest DLI for both seasons. Pearl shade nets do not absorb any spectrum of light, that because of various chromatin and reflective material and transforms direct light into scattered light (Ilic et al., 2019; Shahak et al., 2008), which might explains increased light levels. Gaurav (2014) also found that pearl shade net had the greatest light intensity as compared to red and black shade nets. Similar to our studies, the reduction in transmitted solar radiation also helps to reduce canopy and air temperature under these nets (Ilic et al., 2017). Ilic et al. (2019) also found that shade nets help to reduce solar radiation from 40 to 60% depending upon the time of the day compared to open field conditions. Counce (2021) found that different shade nets helped to reduce solar radiation up to 30 to 45% compared to no shade conditions. In our study, aluminet shade net had the lowest temperature during late spring while black had the lowest temperature during fall. Black shade nets were effective at cooling at greater temperatures. Ahemd et al. (2016) found air temperature reduction of 3 to 4 °C under a black shade net compared to greenhouse air temperature. Ilic et al. (2017) also found that pearl shade nets help to reduce air temperature by 1 °C while black shade nets helped to reduce up to 3 °C. In our study there was an increase in relative humidity under shade nets, the reason for this may be that shade nets traps the water that is transpired from the plant surface. In a study by Ahemd et al. (2016), relative humidity was almost double under shade nets than ambient greenhouse conditions.

Plant growth and quality

Plant height was greatest under no shade and pearl for both basil cultivars during the late spring season, but during fall plant height was greatest under red. Similarly in lettuce, plant height was greatest under red colored nets during both seasons and for both cultivars. Plants can easily sense change in R:Fr ratio and under red shade net there is a lower R:Fr ratio which activates shade avoidance mechanism in plants thus plants grow more in height to get more light and this increases plant height under red shade nets (Franklin, 2008). The reason plant height in basil was greatest under the no shade during late spring was because basil is a warm season crop and needs slightly high temperatures and more light (20 to 25 $mol \cdot m^{-2} \cdot d^{-1}$) for optimum growth (Currey et al., 2020). Ovadia et al. (2015) also found that shading with red colored nets results in longer branches and longer internodes in cut flowers. Oren-Shamir et al. (2001) in Japanese pittosporum (*Pittosporum tobira* T.), also found that red colored shade nets help to increase branching and height of plants. Red light is known to activate red-far red pigment which converts indole acetic acid oxidase

(IAAO) cofactors into kaempferol derivatives, leading to increased apical dominance (Mamford et al., 1961).

Shoot fresh and dry weight was greatest in both basil cultivars and lettuce ‘Lollo Antonet’ under no shade followed by aluminet treatment, whereas aluminet was greatest in ‘Green Forest’ followed by no shade. Shaded plants use more resources to increase the size of their organs to get more sunlight and under full light conditions plants produce a greater number of branches and leaves which increase biomass production (Pierson et al., 1990). Brown et al. (1995) also concluded that plant biomass will decrease, and height will increase under only red light in the absence of blue light. No shade and aluminet treatments provide wavelengths of light which consist of regions ranging from blue to red-far region. Pierson et al. (1990) found similar results which showed increased biomass in cheat grass (*Bromus tectorum* L.) grown under no shade as compared to shade nets. Tafoya et al. (2018) in cucumber (*Cucumis sativus* L.) also found increased biomass production under aluminet colored shade nets. Contradictory to our findings, Yavari et al. (2021) found that red shade helps to increase while aluminet shade decreases plant biomass production in one arabidopsis (*Arabidopsis thaliana* L.) accession, and they hypothesized plants were from different geographical accession for that study and may have had different light quality needs.

Chlorophyll and photosynthesis

Photosynthesis was greatest under aluminet nets during both seasons for lettuce and basil, while chlorophyll concentration in basil was greatest under no shade during both seasons. In lettuce, chlorophyll concentration was greatest under no shade treatment during late spring season while during fall season chlorophyll concentration was greatest under aluminet nets. Plant leaves contain different chloroplast proteins and light activates phosphorylation and protonation between them which affects photosynthesis and chlorophyll concentration (Belkov et al., 2019). Light under aluminet and pearl shade contains red, blue, and green wavelengths which are required by plants and increase efficiency of light due to scattering. The central part of plant chlorophyll contains magnesium atoms which plays an important role to increase chlorophyll synthesis (Bohn et al., 2006). Magnesium concentration was increased under aluminet shade net in lettuce but not basil. Reduced magnesium concentration in plant cells can reduce production of chlorophyll which ultimately can reduce photosynthesis in plants (Fleischer, 1934). Dorenstouter et al. (2008) found magnesium helps in activation of ribulose 1,5-biphosphate carboxylase enzyme which is the main enzyme in photosynthesis of plants. Shahak et al. (2008) found that light scattering through shade nets improves light penetration into the plant canopy which helps to increase various physiological responses such as photosynthesis. Increased photosynthesis under aluminet colored shade net may be due to the presence of red and blue light (Kong et al., 2012) along with reduced temperatures which reduced heat stress. Similar to our finding, Tafoya et al. (2018) found that photosynthesis and stomatal conductance was increased under aluminet and pearl-colored nets in cucumber. In addition, Ilic et al. (2019) found that chlorophyll a/b ratio is greater in unshaded plants as compared to shaded plants in lettuce. They also found that lettuce varieties and plant adaptability to certain environments also affects the synthesis and degradation of chlorophyll in plants. Diaz-Perez and John (2019) also found that chlorophyll index under unshaded plants were greatest as compared to shaded plants in bell pepper (*Capsicum annum* L.).

Nutrients

In this research, lettuce showed greater iron, calcium, and zinc content under no shade while potassium content was greater under pearl nets. Basil showed greatest concentration of calcium under no shade while zinc was greatest under aluminet, iron and potassium did not show any significant differences. Iron, zinc, calcium, and potassium are major nutrients that are required by humans in their daily diet (Eaton et al., 1996). No shade and pearl also showed the greatest amount of light under them. Light is the main factor that controls the opening and closing of stomata which further affects transpiration rate (Aikman and Houter, 1990). High transpiration rate in turn affects uptake, translocation, and distribution of nutrients in plant roots and leaves because roots are in direct contact with nutrients in hydroponic systems (Savvas and Passam, 2002). Xu et al. (2021) also found that light intensity and quality affects the nutrient uptake and crop productivity in arabidopsis. Increased uptake of nutrients in plants would account for increased nutrient concentration in leaves. Counce (2021) also found nutritional concentration are dependent upon season and cultivar in romaine lettuce grown in ebb and flow hydroponics tables. Ryan et al. (1972) in tomato (*Solanum persicum* L.) found that supplemental light radiation helps to increase the nutrient uptake in plants. Zhou et al. (2019) also found that increased light intensity and increased temperature affects nitrogen, phosphorous, and potassium uptake in lettuce. Mou (2009) found that nutritional quality of lettuce leaves is affected by light, temperature, and growing conditions. Similar results were found by Nowak et al. (2006) with increased nutrient concentration in Boston fern (*Nephrolepis exaltata* L.) leaves under high light conditions.

Carbohydrates

Aluminet, pearl, and no shade were all found to increase sugars and °Brix concentrations. Carbohydrates are made through the process of photosynthesis using light energy (Ma et al., 2016). Huber (1981) found plants use photosynthesis to convert carbon into sugars and starches. Plants use the Calvin cycle in the process of photosynthesis which provide energy for plants and also generates triosephosphate which initiates carbohydrate formation (Taiz and Zeiger, 1991). Triosephosphate and dihydroxyacetone phosphate translocated from chloroplasts and combines which for aldol to produce fructose, which further turns into glucose (Halford et al., 2010).

In our study, photosynthesis rate was greatest under aluminet and pearl nets and photosynthesis is known to directly correlate to sugar concentration. Li et al (2013) found that increased sugar content in lettuce leaves increase sweetness which favors consumer preference. Zhian et al. (1994) found increased sugars concentration under greater light intensity in ginseng

(*Panax quinquefolius* L.). In a study by Huang et al. (2017) high light intensity of blue light also helped to increase sugar concentration of oyster mushroom (*Lentinus sajor-caju* L.). In our study aluminet and pearl nets also had blue light reflection percentage ranging from 50 to 65%. Starches are stored as energy and can be converted to sugars (maltose) and these sugars provide energy for plant growth and development (Halford et al., 2010). This might be the reason our starch levels are low in treatments where sugars are high. Halford et al. (2010) also found that sugar and starch content is highly dependent on genetic constituent of different cultivars. In our study °Brix and carbohydrates were not correlated. Plants contain different pool of soluble sugars (glucose, fructose, sucrose, galactose, and maltose) and polysaccharides like starch (Chow and Landhausser, 2004). The anthrone regent method analyzed all soluble sugars and starches, while °Brix only measures sucrose values in plant leaves. °Brix measures is the percent weight of total soluble sugars present in a sucrose solution (Dongare et al., 2015; Thakulla et al., 2021). And is commonly used to measure total soluble solid in different fruits and vegetables.

Conclusion

In conclusion, this study is consistent with other findings that colored shade nets help to increase plant height, photosynthesis, and chlorophyll concentration in lettuce and basil vegetable species. In contrast, biomass, yield, and nutrient concentration of basil and lettuce leaves was greatest under no shade which was recommended light and temperature levels for both species. Colored shade nets having red colored light (aluminet, pearl, and red) are best to increase photosynthesis and sugar concentration while no shade is best to increase biomass and nutrient concentration in lettuce and basil leaves. Basil ‘Genovese’ and lettuce ‘Green Forest’ cultivars had greatest amount of nutrients. Both basil cultivars had greater shoot fresh and dry weight in fall, while both lettuce cultivars grew better in the late spring.

Table 2.1. Greenhouse conditions for daily light integral, temperature, and relative humidity under aluminet, black, pearl, and red colored shade nets with no shade treatments for late spring and fall season in Stillwater, OK in 2021.

Season	Treatment	Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)	Temperature (°C)	Relative humidity (%)
Late spring	No shade	20.6a[z]	30.6b	63.4b
	Aluminet	12.2c	29.7c	64.9a
	Black	9.6d	30.4b	63.8ab
	Pearl	16.6b	30.6b	62.9b
	Red	12.9c	31.3a	61.2c
Fall	No shade	24.2a	26.8a	55.8d
	Aluminet	17.3c	24.3b	66.6a
	Black	10.2e	23.9b	65.3b
	Pearl	20.3b	25.3a	63.1c
	Red	13.7d	25.2a	20.8e

[z]Within a column followed by same lowercase letter are not significantly different by pairwise comparison ($P \leq 0.05$).

Table 2.2. Summary ANOVA table for different growth and quality parameters under aluminet, black, pearl, and red colored shade nets with no shade treatments in leaves of basil and lettuce cultivars grown in ebb and flow tables under greenhouse conditions during late spring and fall season in Stillwater, OK in 2021.

Source	Season	Cultivar	Treatment	Season × Cultivar	Season × Treatment	Cultivar × Treatment	Season × Cultivar ×Treatment
Basil							
Shoot fresh weight	***[z]	***	***	***	*	NS	NS
Shoot dry weight	***	***	***	NS	*	***	NS
Plant height	***	**	***	**	***	NS	*
Root fresh weight	NS	***	***	NS	NS	***	NS
Root dry weight	NS	***	***	NS	NS	NS	NS
Photosynthesis rate	***	***	***	NS	**	*	NS
Chlorophyll concentration	***	NS	***	*	**	NS	NS
Lettuce							
Shoot fresh weight	***[z]	***	***	***	***	**	NS

Shoot dry weight	NS	***	***	**	***	***	NS
Plant height	***	***	***	***	***	***	***
Root fresh weight	NS	***	***	NS	NS	***	NS
Root dry weight	NS	NS	NS	NS	NS	NS	NS
Photosynthesis rate	NS	***	***	NS	*	***	NS
Chlorophyll concentration	***	***	**	NS	*	NS	***

[z]Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

Table 2.3. Interaction between season, cultivar, and treatment for plant height and chlorophyll concentration in basil and lettuce cultivars grown under aluminet, black, pearl, and red colored shade nets with no shade treatments in ebb and flow hydroponic systems under greenhouse conditions during late spring and fall season in Stillwater, OK in 2021.

Species	Season	Cultivar	Treatment	Plant height (cm)	Chlorophyll concentration (Unitless)
Basil	Late spring	Aroma-2	No shade	31.7bcdefg[z]	33.9a
			Aluminet	21.4hi	31.7a
			Black	19.1i	30.8a
			Pearl	27.4efghi	31.9a
			Red	24.6ghi	29.7a
		Genovese	No shade	32.5bcdefg	34.1a
			Aluminet	26.8efghi	31.4a
			Black	28.2defgh	31.0a
			Pearl	34.1bcdef	31.2a
			Red	26.0fghi	31.9a
	Fall	Aroma-2	No shade	39.1abc	41.8a
			Aluminet	35.3bcde	40.1a
			Black	30.6cdefg	41.5a
			Pearl	36.3bcd	43.1a
			Red	40.0ab	36.3a
		Genovese	No shade	39.1abc	43.4a
			Aluminet	31.0cdefg	37.5a
			Black	30.7cdefg	38.0a
			Pearl	34.6bcde	41.3a
			Red	45.9a	33.9a
Lettuce	Late spring	Lollo Antonet	No shade	17.5b	21.1g
			Aluminet	17.1b	19.0g
			Black	18.4b	22.0g
			Pearl	17.1b	19.2g
			Red	19.2b	18.8g

	Green Forest	No shade	22.8b	43.4abcd
		Aluminet	25.4b	38.1de
		Black	26.6b	38.3cde
		Pearl	27.6b	39.0bcde
		Red	29.7b	38.5bcde
Fall	Lollo Antonet	No shade	9.7b	33.7ef
		Aluminet	20.5b	32.4ef
		Black	15.9b	26.3fg
		Pearl	10.6b	33.5ef
		Red	20.8b	25.4fg
	Green Forest	No shade	19.4b	45.8ab
		Aluminet	66.9a	49.9a
		Black	65.8a	48.4a
		Pearl	19.2b	47.3a
		Red	89.9a	45.6abc

[z]Means (n = 18) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.4. Interaction between cultivar and treatment on shoot fresh weight, shoot dry weight, root fresh weight, and photosynthesis rate of two cultivars of basil and lettuce grown under aluminet, black, pearl, and red colored shade nets with no shade treatments during late spring and fall seasons in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Cultivar	Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	CO_2 assimilation rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$)
Basil	Aroma-2	No shade	42.4a[z]	6.2b	18.9b	19.3b
		Aluminet	32.0a	4.2de	6.4e	23.9a
		Black	18.8a	3.9de	6.4e	20.8b
		Pearl	23.5a	4.8cd	12.0cd	18.0bc
		Red	26.7a	3.7e	8.8de	15.4cd
	Genovese	No shade	48.1a	8.3a	34.7a	18.5b
		Aluminet	33.5a	5.2c	13.8c	20.1b
		Black	24.0a	4.5cde	12.7c	18.9b
		Pearl	28.5a	5.3bc	22.1b	18.5b
		Red	31.7a	5.3c	14.4c	12.8d
Lettuce	Lollo Antonet	No shade	66.8bc	7.8bcd	17.3c	7.6de
		Aluminet	62.6bc	8.1bc	8.0d	10.5c
		Black	37.7e	4.9e	9.0d	8.7cd
		Pearl	39.7e	6.1de	15.1c	9.5cd
		Red	57.2cd	6.8cd	8.5d	5.7e
	Green Forest	No shade	76.7b	10.8a	33.2a	18.1a
		Aluminet	95.4a	6.8cd	10.1d	17.2ab
		Black	43.2de	4.9e	9.6d	18.2a
		Pearl	51.5cde	9.2ab	28.6b	17.3ab
		Red	76.5b	7.7bcd	15.2c	15.5b

[z]Means (n = 18) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.5. Interaction between season and treatment on shoot fresh weight, shoot dry weight, photosynthesis rate, and chlorophyll concentration of basil and lettuce grown under aluminet, black, pearl, and red colored shade nets with no shade treatments during late spring and fall seasons in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Season	Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	CO_2 assimilation rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Chlorophyll concentration (unitless)
Basil	Late spring	No shade	39.6b[z]	6.4b	16.7de	33.9cd
		Aluminet	27.0cd	3.9de	20.2bc	31.6d
		Black	13.8e	3.4e	18.6bcd	30.9d
		Pearl	16.5e	4.7cd	18.1cd	31.6d
		Red	18.8de	3.9de	13.6f	30.8d
	Fall	No shade	50.9a	8.1a	21.2ab	42.6a
		Aluminet	38.5b	5.5c	23.8a	38.8b
		Black	28.9c	5.0c	20.9bc	39.7ab
		Pearl	35.4bc	5.4c	18.4bcd	42.2a
		Red	39.6b	4.9c	14.6ef	35.1c
Lettuce	Late spring	No shade	117.1a	9.7a	13.8a	32.2cd
		Aluminet	108.9ab	6.7de	13.8a	28.6d
		Black	63.2c	5.7ef	13.5a	30.2d
		Pearl	61.9c	8.3abc	13.1ab	29.1d
		Red	95.8b	7.2cde	10.2c	28.7d
	Fall	No shade	26.4ef	8.9ab	11.9abc	39.7ab
		Aluminet	49.1cd	8.2abcd	13.9a	41.2a
		Black	17.7f	4.2f	13.4a	37.3ab
		Pearl	29.2ef	7.1cde	13.7a	40.4ab
		Red	37.9de	7.3bcde	11.0bc	35.5bc

[z]Means (n = 18) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.6. Interaction between season and cultivar on shoot fresh weight, shoot dry weight, and chlorophyll concentration of two cultivars of basil and lettuce grown under aluminet, black, pearl, and red colored shade nets with no shade treatments during late spring and fall seasons in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Season	Cultivar	Shoot fresh weight (g)	Shoot dry weight (g)	Chlorophyll concentration (unitless)
Basil	Late spring	Aroma-2	16.5c[z]	3.8a	31.6c
		Genovese	29.9b	5.1a	31.9c
	Fall	Aroma-2	40.8a	5.3a	40.5a
		Genovese	36.5a	6.3a	38.8b
Lettuce	Late spring	Lollo Antonet	93.5a	7.8a	20.0d
		Green Forest	85.5a	7.2a	39.5b
	Fall	Lollo Antonet	43.9b	8.0a	30.3c
		Green Forest	20.2c	6.2b	47.4a

[z]Means (n = 18) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.7. Summary ANOVA table for nitrogen (%), phosphorous (%), calcium (%), potassium (%), magnesium (%), sulfur (%), boron (ppm), iron (ppm), zinc (ppm), copper (ppm), and manganese (ppm) under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Source	Cultivar	Treatment	Cultivar × Treatment	Cultivar	Treatment	Cultivar × Treatment
Basil				Lettuce		
Nitrogen	***[z]	NS	NS	**[z]	NS	NS
Phosphorous	*	*	NS	***	NS	NS
Calcium	**	*	NS	***	**	NS
Potassium	*	NS	*	***	***	NS
Magnesium	NS	NS	NS	***	***	**
Sulfur	NS	NS	NS	*	***	NS
Boron	***	***	NS	**	NS	NS
Iron	NS	NS	NS	**	NS	**
Zinc	*	*	NS	*	*	NS
Copper	***	NS	NS	**	NS	**

Manganese	***	**	NS		***	*	***

[z]Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

Table 2.8. Cultivar × Treatment interaction for potassium, magnesium, iron, copper, and manganese under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Cultivar	Treatment	Potassium (%)	Magnesium (%)	Iron (ppm)	Copper (ppm)	Manganese (ppm)
Basil	Aroma-2	No shade	5.7ab[z]	0.74a	97.1a	8.9a	84.3a
		Aluminet	4.8b	0.67a	136.9a	14.5a	97.1a
		Black	6.9a	0.62a	102.1a	7.7a	105.2a
		Pearl	6.5ab	0.74a	108.5a	6.9a	75.3a
		Red	6.5ab	0.73a	118.9a	6.7a	72.8a
	Genovese	No shade	5.2ab	0.86a	76.6a	9.8a	105.1a
		Aluminet	6.5ab	0.68a	84.9a	12.7a	114.6a
		Black	5.7ab	0.76a	147.1a	10.8a	137.7a
		Pearl	6.0ab	0.72a	224.0a	7.9a	68.2a
		Red	6.7a	0.69a	136.9a	9.0a	81.2a
Lettuce	Green Forest	No shade	7.5a	0.66a	248.5a	10.0a	283.7a
		Aluminet	5.7a	0.48bc	64.1b	6.4abc	58.3d
		Black	7.6a	0.45c	73.6b	3.9c	69.5d
		Pearl	9.9a	0.62ab	177.5ab	7.9ab	148.4bc
		Red	8.0a	0.46bc	70.5b	5.1bc	77.5d
	Lollo Antonet	No shade	5.6a	0.60abc	85.6b	5.3bc	154.9b
		Aluminet	4.7a	0.72a	85.8b	7.2abc	87.4cd
		Black	5.2a	0.65b	143.4ab	5.9bc	87.2cd
		Pearl	7.0a	0.61abc	109.1b	7.6abc	108.4bcd
		Red	6.3a	0.57abc	68.2b	5.8bc	102.0bcd

[z]Means (n = 6) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.9. Main effects of cultivar on phosphorous, calcium, potassium, sulfur, boron, zinc, and manganese under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Treatment	Phosphorous (%)	Calcium (%)	Potassium (%)	Sulphur (ppm)	Boron (ppm)	Zinc (ppm)	Manganese (ppm)
Basil	Aroma-2	0.98b[z]	1.04b	6.1a	0.34a	19.8b	52.3b	86.9b
	Genovese	1.11a	1.22a	6.0a	0.38a	23.8a	61.5a	101.4a
Lettuce	Green Forest	0.73a	0.78a	7.7a	0.38a	24.3a	69.9a	127.5a
	Lollo Antonet	0.72a	0.68b	5.8b	0.27b	25.6a	52.5b	107.9b

[z]Means (n = 6) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.10. Main effects of treatment on nitrogen, phosphorous, calcium, potassium, sulfur, boron, zinc, copper, and manganese under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Treatment	Nitrogen (%)	Phosphorous (%)	Calcium (%)	Potassium (%)	Sulfur (ppm)	Boron (ppm)	Zinc (ppm)	Copper (ppm)	Manganese (ppm)
Basil	No shade	4.17c[z]	1.02ab	1.38a	5.4a	0.40a	20.3bc	55.1ab	9.4b	94.7abc
	Aluminet	4.80b	1.05ab	1.11ab	5.7a	0.39a	26.0a	67.2a	13.6a	105.9ab
	Black	5.36a	1.23a	1.00b	6.3a	0.38a	24.3ab	60.2ab	9.2b	121.4a
	Pearl	4.53bc	0.95b	0.99b	6.3a	0.31a	19.4c	49.2b	7.4b	71.7c
	Red	4.71b	0.98b	1.16ab	6.6a	0.33a	18.4c	52.9ab	7.9b	77.0bc
Lettuce	No shade	4.36ab	0.78a	0.95a	6.5b	0.34ab	26.3ab	82.6a	7.6ab	219.3a
	Aluminet	4.43ab	0.64b	0.63b	5.2c	0.35ab	27.8a	47.5ab	6.8abc	72.9c
	Black	4.81a	0.64b	0.64b	6.4b	0.36a	28.0a	45.2b	4.9c	78.4c
	Pearl	4.72a	0.83a	0.68b	8.5a	0.30ab	22.6ab	61.5ab	7.8a	128.4b
	Red	4.24b	0.72ab	0.74b	7.2b	0.25b	19.7b	69.4ab	5.5bc	89.7bc

[z]Means (n = 6) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.11. Summary ANOVA table for sugars (mg·g) and starch (mg·g) under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Source	Season	Cultivar	Treatment	Season × Cultivar	Season × Treatment	Cultivar × Treatment	Season × Cultivar × Treatment
Basil							
Sugar	***[z]	NS	***	***	***	***	***
Starch	***	**	***	***	***	***	***
°Brix	NS	***	***	NS	NS	NS	NS
Lettuce							
Sugar	***	***	***	NS	***	NS	***
Starch	*	*	***	NS	***	*	*
°Brix	***	***	***	***	NS	NS	NS

[z]Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

Table 2.12. Interaction between season, cultivar, and treatment for sugar and starch under aluminet, black, pearl, and red colored shade nets with no shade treatment during late spring and fall seasons in basil and lettuce nets in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.

Species	Season	Cultivar	Treatment	Sugar (mg·g)	Starch (mg·g)
Basil	Late spring	Aroma-2	No shade	40.7de[z]	30.6a
			Aluminet	54.2d	9.3bcde
			Black	15.7f	7.4cde
			Pearl	29.9ef	8.3bcde
			Red	32.5ef	16.0b
		Genovese	No shade	33.1def	12.9bcd
			Aluminet	20.6ef	3.3e
			Black	27.2ef	6.98cde
			Pearl	23.5ef	4.7e
			Red	24.6ef	9.1bcde
	Fall	Aroma-2	No shade	113.1b	9.5bcde
			Aluminet	24.5ef	7.9bcde
			Black	28.0ef	4.0e
			Pearl	134.2b	2.9e
			Red	28.2ef	5.7de
		Genovese	No shade	87.6c	14.2bc
			Aluminet	15.8f	3.9e
			Black	25.8ef	12.9bcd
			Pearl	186.4a	2.4e
			Red	32.5ef	7.8cde
Lettuce	Late spring	Lollo Antonet	No shade	80.7bcde	3.7b
			Aluminet	129.9a	6.8b
			Black	98.6abcd	2.5b
			Pearl	33.9fg	2.2b
			Red	66.2cdef	2.2b
		Green Forest	No shade	33.7fg	1.7b
			Aluminet	107.2abc	3.4b
			Black	48.7efg	1.8b

		Pearl	21.7g	1.4b
		Red	79.9bcde	2.8b
Fall	Lollo Antonet	No shade	92.8abcd	2.5b
		Aluminet	117.4ab	2.7b
		Black	99.9abcd	2.2b
		Pearl	108.5ab	19.4a
		Red	95.3abcd	2.4b
	Green Forest	No shade	119.8ab	3.8b
		Aluminet	58.5defg	2.3b
		Black	100.6abc	1.2b
		Pearl	48.7efg	7.9b
		Red	29.2fg	2.9b

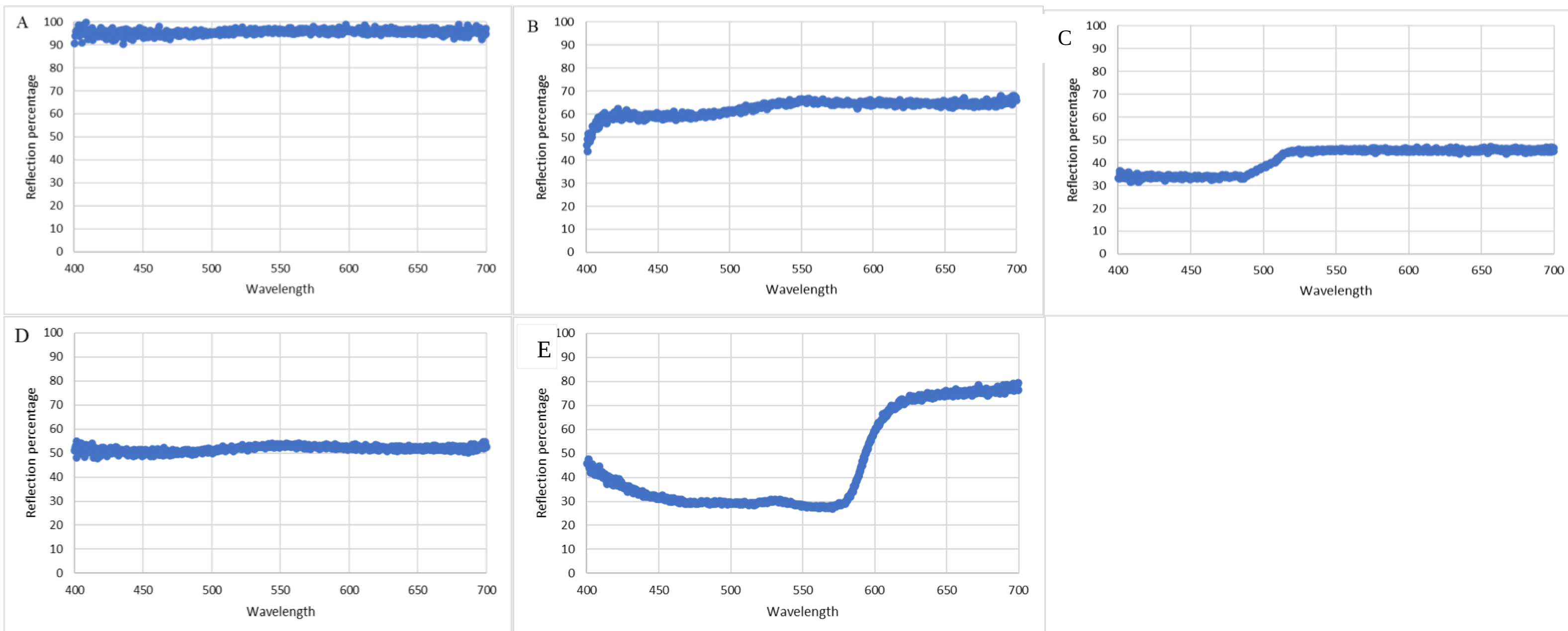
[z]Means (n = 6) within a column and species followed by same lowercase letter are not significantly different by pairwise comparison in mixed model ($P \leq 0.05$).

Table 2.13. Correlation analysis between °Brix, sugars, and starches in lettuce (‘Lollo Antonet’ and ‘Green Forest’) and basil (‘Aroma-2’ and ‘Genovese’) cultivars grown under greenhouse and shade net conditions during late spring and fall season in Stillwater, OK 2021.

	Late spring				Fall			
Cultivar	Source	Sugar	Starch	°Brix	Source	Sugar	Starch	°Brix
Lollo Antonet	Sugar	1.00	-	-	Sugar	1.00	-	-
	Starch	0.06	1.00	-	Starch	0.28	1.00	-
	°Brix	-0.05	-0.02	1.00	°Brix	-0.04	-0.06	1.00
Green Forest	Sugar	1.00	-	-	Sugar	1.00	-	-
	Starch	0.08	1.00	-	Starch	0.07	1.00	-
	°Brix	-0.02	-0.23	1.00	°Brix	0.17	-0.18	1.00
Aroma-2	Sugar	1.00	-	-	Sugar	1.00	-	-
	Starch	0.41*	1.00	-	Starch	-0.10	1.00	-
	°Brix	0.34	0.31	1.00	°Brix	0.34	0.32	1.00
Genovese	Sugar	1.00	-	-	Sugar	1.00	-	-
	Starch	-0.20	1.00	-	Starch	-0.17	1.00	-
	°Brix	0.40	-0.12	1.00	°Brix	0.35	-0.24	1.00

[z]Indicates 0 to 0.39= Weak positive correlation, 0.40 to 0.60= Slightly positive correlation.

Figure 2.1. Reflectance percentage in different wavelengths of light under no shade (A) and 50% shading intensity of aluminet (B), black (C), pearl (D), and red (E) colored shade nets during late spring and fall seasons in basil and lettuce in ebb and flow hydroponic systems under greenhouse conditions in Stillwater, OK in 2021.



CHAPTER III

USING COLORED SHADE NETS TO IMPROVE QUALITY ASPECTS OF POTTED ORNAMENTALS

Abstract

The color of shade is known to impact plant growth and quality depending on the amount and quality of light reflected. Four different ornamental plants species (celosia, begonia, gerbera, and fountain grass) were selected and grown under aluminet, pearl, and red shade nets plus black as the control at 50% shade intensity. Measurements of plant height, chlorophyll concentration, photosynthetic activity, flower number, shoot fresh, and dry weight was evaluated at 8 weeks after transplanting. Pearl colored shade nets had greatest light intensity which was 40%, 20%, and 30% greater than black, aluminet, and red shade nets, respectively. The aluminet colored net resulted in the greatest shoot fresh weight, dry weight, photosynthesis, and chlorophyll concentration. Aluminet colored net showed a 20% increase in shoot dry weight in begonia and celosia as compared to black colored nets, while pearl and red were not significantly different. Aluminet colored net was best to promote growth and quality of ornamental plants except plant height in

fountain grass which was greatest under red and black while flower number remained unaffected under different colored nets.

Introduction

The floriculture industry occurs on a global scale and includes cut flowers, bedding plants, foliage plants, hanging baskets, and potted flowering plants. In the United States, Florida and California are the two leading states which produce nearly half of the floriculture production (USDA, 2021). The United States imports nearly 70% of flowers from Colombia, Ecuador, and the Netherlands, because these countries have larger and warmer growing seasons which allows them to produce high yields and more reliable products (Crowley, 2007). In the United States, mostly flowering potted plants are grown inside controlled environments using different flats, trays, pots, and hanging baskets to provide optimum environmental conditions (Hall and Willis, 2006).

In greenhouse production, one of the difficult tasks is to maintain optimum environmental conditions during very hot and sunny period of the year because solar radiation is trapped and converted into latent heat inside the greenhouse (Ahemd et al., 2016). Temperature, water, and nutrients can be controlled easily (Gaurav, 2014), but light intensity is very hard to control because light is a variable factor and light intensity varies due to season and location (Belkov et al., 2019). Each crop has its own ideal light requirements in which photosynthesis and plant growth is maximized and too high and too low levels of light can affect plants in negative ways (Torres and Lopez, 2012). Colored shade nets are a common technology that can help to alter the light spectrum and provide optimum light conditions for plant growth (Shahak, 2008).

Colored nets are woven or knitted and are available in various textures, designs, and longevities according to the material used and are widely used in commercial production (Shahak et al., 2004; Ntsoane et al., 2016). Photoselective shade nets are made from ultra-violet (UV) resistant plastic and help to filter different wavelengths of light (Shahak et al., 2008) and each shade net can modify spectral properties and uniquely scatter incoming radiation to plants (Ganelevin et al., 2008). Colored shade nets provide free airflow and therefore cause minimal interference with the microclimate of plants (Gaurav, 2014). These shade nets are used to reduce light intensity and routinely scatter incoming light by up to 50% (Stamps, 2009; Diaz-Perez et al., 2020). Under field conditions, shade nets are also used to protect plants from environmental hazards such as hail, strong winds, sandstorms, and various insect-pests (Shahak et al., 2004).

Shade net effects are varied according to the crops and environmental conditions in which a crop is grown. In a study by Stamps and Chandler (2008), cast iron plant (*Aspidistra elatior* L.) performed best under black colored shade nets while Japanese pittosporum (*Pittosporum tobira* T.) performed best under red colored shade net. Hernandez et al. (2020) found lisianthus (*Eustoma grandiflorum* D.) had longer stems with greatest diameter under red colored shade nets while leaf area was greatest under blue colored shade nets. Similarly, Gaurav (2014) found that corn plant (*Draceana fragrans* L.) performed best under red colored shade net for various growth parameters. In the same study, ti plant (*Cordyline fructiosa* L.) performed best under white colored shade nets. Colored shade nets appear to be species dependent. Thus, the objective of this study was to identify the best colored shade nets for growth and flowering of common potted ornamental plants.

Materials and methods

Location and greenhouse conditions. A greenhouse experiment was conducted at the research greenhouse facility at Oklahoma State University, Stillwater campus (36.1361,-97.0863). No supplemental light was used in the greenhouse, daily light integral levels (DLI) averaged 17.2 ± 2.1 $mol \cdot m^{-2} \cdot d^{-1}$. The average temperature was set at 21/18 °C in greenhouse and average temperature was 30.5 ± 1.2 °C.

Plant material and treatments. Seedling of celosia (*Celosia cristata* L.) 'Fresh Look Orange', begonia (*Begonia tuberhybrida* L.) 'Olympia Red', fountain grass (*Pennisteum alopecurold* L.), and gerbera (*Gerbera jamesonii* H.) 'Jaguar White' were obtained from Ball Horticulture (West Chicago, IL) in 288 cell trays. Celosia, fountain grass, begonia, and gerbera plugs were received on 13 May 2021 and potted on 17 May 2021. All plants were transplanted into 15 cm pots filled with growing media (BM-7, 45% bark, Berger, Sulphur Late springs, TX). Pots were spaced at 30 cm spacing. Polyvinyl chloride (PVC) pipes of 2.5 cm diameter were used to make frames of 0.762 m height to hold shade nets above the canopy. Shade net treatments included red, aluminet, pearl, and black as the control shade nets (Green-Tek, Janesville, WI) with 50% light intensity. Water was provided to plants when required with drip irrigation pressure compensation emitters at 2 gph. A 15N-3.9P-10.4K (5-6 months) slow-release fertilizer (Osmocote Plus, Dublin, OH) was used at a rate of 200 $mg·L^{-1}$ nitrogen and 20% leaching fraction.

Data collection. Data was collected 6 weeks after transplanting for celosia and begonia which were harvested on 28 June 2021. Fountain grass and gerbera were harvested after 8 weeks on 12 July 2021. Measurements of plant height (from top of the pot), flower number, fresh weight and dry weight were conducted at harvest. For dry weights, plant material was oven-dried for 2 d at 53.9 °C. Chlorophyll measurements were made by using a chlorophyll meter (Minolta SPAD-502, Spectrum Technologies, IL), data was collected and averaged by inserting the upper, middle, and base portion of a leaf in the sensor. Carbon dioxide assimilation rate was measured using a Li-Cor 6400XT (Li-Cor biosciences Lincoln, NE) at a light intensity of 1000 $\mu mol·m^{-2}·s^{-1}$ on a single leaf taken from middle of the plant. Spectral data for reflectance was measured after 2 weeks of transplanting in the middle of the day using a spectrometer HL-2000- FHSA (Ocean Optics, Shangai, China). Illuminance, temperature, and humidity was recorded using a datalogger (Illuminance UV recorder TR-74Ui T&D, Matsumoto, Japan).

Statistical analysis. The experiment was set up as a randomized complete block design with 10 plants per treatment, and the experiment was replicated in greenhouse at the same time. The experimental units were 10 plants per cultivar per treatment. For the end measure responses, mixed models method was used since unequal variance was evident among the treatment levels. Tukey pairwise comparisons of significant effects were performed, all tests were conducted at the 0.05 level of significance and all data were analyzed using SAS 9.4 software.

Results

Light intensity and quality, temperature and relative humidity

There were significant differences between different shade nets for dailt light integral (DLI), temperature, and relative humidity (Table 3.1). Pearl showed the greatest DLI while light levels were lowest in black. Aluminet net had the lowest temperature while light levels were greatest under red. Relative humidity was greatest under aluminet and black nets. Black shade net had minimum reflectance with blue light nearly 30%, yellow and green up to 40%, and red light approximately 25% (Figure 3.1). Pearl shade net had reflection percentage ranging from 60 to 70% for all wavelengths of light while aluminet shade net had 55% reflection for all wavelengths. Red shade net had 35% reflection percentage of blue, green, and yellow light while red light had 75 to 80% reflection percentage.

Begonia

Shoot fresh weight, shoot dry weight, carbon dioxide (CO_2 assimilation rate, and chlorophyll concentration showed significant differences under different colored treatments in begonia (Table 3.2). Shoot dry and fresh weight was greatest in aluminet but was only different from the black treatment (Table 3.3). The red treatment showed the greatest photosynthesis rate although not different from aluminet or pearl. Chlorophyll concentration was greatest under pearl although this was not different than aluminet.

Celosia

In celosia, shoot fresh weight, shoot dry weight, CO_2 assimilation rate, and chlorophyll concentration showed significant differences between different treatments (Table 3.2). Shoot fresh weight and chlorophyll concentration were greatest in aluminet which were different from all other treatments (Table 3.3). Shoot dry weight showed greatest value under aluminet but was not different than pearl. Aluminet also showed the greatest CO_2 assimilation rate which was different from black and pearl treatments. chlorophyll concentration was greatest under aluminet. Overall aluminet, pearl, and red colored shade nets containing red light improved growth and quality parameters in this study.

Gerbera

Carbon dioxide assimilation rate and chlorophyll concentration showed significant differences between treatments (Table 3.2). Carbon dioxide assimilation rate was greatest under pearl treatment which was only different from red (Table 3.3). While aluminet showed greatest chlorophyll concentration values but was not different than black. Overall, pearl and black colored shade nets showed increased concentration of chlorophyll and photosynthesis.

Fountain grass

Shoot fresh weight, plant height, and chlorophyll concentration showed significant differences between different treatments in fountain grass (Table 3.2). Pearl showed greatest shoot fresh weight which was only different than black (Table 3.3). While plant height was greatest under black which was not different than red. chlorophyll concentration showed greatest values under aluminet which was different from pearl treatment. Overall, aluminet and red colored shade net showed greatest shoot fresh weight, plant height, and chlorophyll concentrations.

Discussion

In our study, pearl showed the greatest DLI as compared to other shade nets, while DLI was lowest with black. Pearl shade nets had the most reflectance of light thus amount of DLI, while black shade absorbs all the radiation and had the lowest reflection percentage and DLI. Aluminet net had greatest shoot dry weight for begonia and celosia while gerbera and fountain grass did not show any significant differences indicating a species by treatment interaction. Crowley (2007) also found that snapdragon, pansy, and celosia varied in their responses to different colored plastic films. After red colored shade nets, aluminet and pearl colored shade nets transmit the greatest amount of red light (Tafoya et al., 2018). Celosia needs (14 to18 mol· $m^{-2}·d^{-1}$) of light which might also explain increased shoot dry weight under aluminet shade (Torres and Lopez, 2012). Shade nets are used to either reduce light intensity as a whole because photosynthetic photon flux (PPF) > 1000 increases photorespiration and heat stress, this could be the reason that shoot fresh and dry weight was greatest under aluminet nets. Pearl and aluminet are neutral colors having 50 to 60% of blue and green light and red light only had 20% blue wavelength. A combination of red and blue may promote growth more than just red. Ohashi-Kaneko et al. (2010) found that red and blue light together promotes growth of rice (*Oryza sativa* L.) as compared to red light alone. Black colored shade nets are opaque and do not have any effect on spectral modification of light (Ilic et al., 2017). Similar to our studies, Rupasinghe et al. (2015) found that aluminet shade nets helped to increase rose (*Rosa hybrida* L.) yield as compared to black and no shade conditions. Hou et al. (2018) alsofound increased fresh weight and flavonoid contents in rose grown under shade nets as compared to no shade nets.

Plant height was only affected in fountain grass which showed increased height under black and red shade nets. Fountain grass is a C4 plant while celosia, begonia, and gerbera are C3 plant species. This might be the reason that plant height was affected in only fountain grass. C4 plants can Tolerate higher light intensity and temperature as compared to C3 plants this could increase more height in fountain grass. Pearcy et al. (1981) found that greater light level and temperature can affect photosynthesis differently in between C3 and C4 plants, leading to more growth in C4 plants. Ovadia et al. (2015) found increased stem length in different cut flower species under red colored shade nets.

Photosynthesis did not show any clear pattern but was greatest under aluminet and pearl shade nets. This might be because every species has its own photosynthesis processes under different light quality and quantity. Plants under shade have greatest leaf area which leads to increased photosynthesis because plants more leaf area can receive more light (Ilic et al., 2018). Shahak et al. (2008) found that shading with colored shade nets caused minimum interference with the microclimate of plants and increase light use efficiency in plants helping to increased biomass and photosynthesis (Shahak et al., 2008). Chlorophyll concentration was greatest under aluminet except celosia in which chlorophyll was greatest under pearl net. In cordyline (*Cordyline fructiosa* L.), Gaurav (2014) also found increased concentrations of chlorophyll and photosynthetic activity under pearl nets. Counce (2021) found chlorophyll concentration is directly related to photosynthesis, with pearl and aluminet nets resulting in the greatest chlorophyll concentration and black colored shade nets having the lowest chlorophyll concentrations in lettuce (*Lactuca sativa* L.) leaves.

Conclusion

In this study, the color of photoselective shade nets had significant effects on growth and development of ornamental plant species, but flowering remained unaffected. Aluminet colored net had increased shoot fresh weight, dry weight, photosynthesis and chlorophyll concentration while these were lowest under black colored net. Black and red shade nets were found to increase plant height in fountain grass. Aluminet colored shade nets would be recommended for greenhouse production of celosia, begonia, and gerbera for increased shoot biomass. Future studies should evaluate different shade net percentages, locations in addition to timing of year and relation to light and temperature level interactions with plant growth.

Table 3.1. Greenhouse conditions for daily light integral, temperature, and relative humidity under aluminet, black, pearl, and red colored shade nets under greenhouse conditions in Stillwater, OK during summer 2021.

Treatment	Daily light integral ($mol\cdot m^{-2}\cdot d^{-1}$)	Temperature (°C)	Relative humidity (%)
Black	12.4c[z]	30.4b	63.8ab
Aluminet	18.5b	29.7c	64.9a
Pearl	22.7a	30.6b	62.9b
Red	15.3c	31.3a	61.2c

[z]Within a column followed by same lowercase letter are not significantly different by pairwise comparison ($P \leq 0.05$).

Table 3.2. Summary ANOVA table of main effects of treatment for different growth and quality parameters of begonia, celosia, gerbera and fountain grass under aluminet, black, pearl, and red colored shade nets greenhouse conditions in Stillwater, OK during summer 2021.

Source	Begonia	Celosia	Gerbera	Fountain Grass
Shoot fresh weight	0.014[z]	0.001	0.071	0.023
Shoot dry weight	0.013	0.018	0.255	0.286
Plant height	0.106	0.101	0.081	0.001
Flower number	0.483	0.275	0.060	0.346
CO_2 assimilation rate	0.001	0.001	0.040	0.139
Chlorophyll concentration	0.002	0.001	0.001	0.001

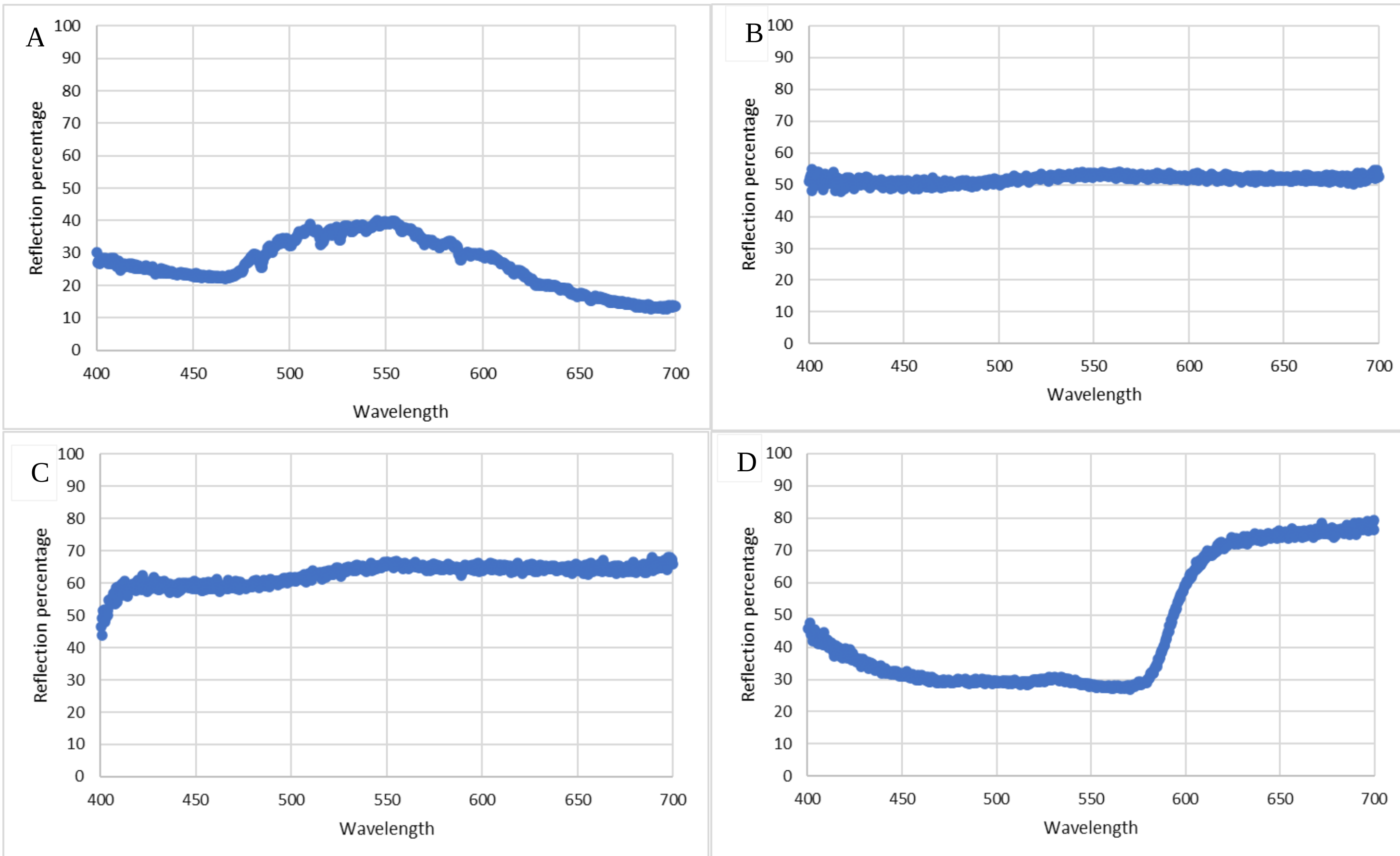
[z]Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

Table 3.3. Main effects of treatment on shoot fresh weight, shoot dry weight, plant height, CO_2 assimilation rate, and chlorophyll concentration in celosia 'Fresh Look Orange', begonia 'Olympia Red', fountain grass (Pennisteum sp.), gerbera 'Jaguar White' grown under aluminet, black, pearl, and red colored shade nets in Stillwater, OK in summer 2021.

Species	Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	Plant height (cm)	CO_2 assimilation rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Chlorophyll concentration (unitless)
Begonia	Black[z]	63.8b	9.6b	19.0a	12.4b	33.1b
	Aluminet	71.3a[z]	10.7a	19.8a	18.9a	36.5a
	Pearl	66.5ab	9.9ab	17.7a	19.2a	37.8a
	Red	67.5ab	10.1ab	20.0a	20.1a	32.5b
Celosia	Black	84.3b	11.2b	28.0a	10.3c	35.7b
	Aluminet	110.1a	13.6a	25.4a	22.3a	38.1a
	Pearl	90.9b	11.3ab	26.0a	20.2b	35.4b
	Red	90.5b	11.1b	26.0a	20.8ab	34.3b
Gerbera	Black	79.5a	11.1a	22.8a	22.3ab	42.5ab
	Aluminet	98.0a	12.6a	21.8a	23.2ab	44.9a
	Pearl	95.9a	13.0a	20.7a	23.8a	40.9b
	Red	89.3a	11.7a	21.6a	20.3b	39.5b
Fountain grass	Black	68.7b	10.6a	111.1a	24.1a	43.5a
	Aluminet	90.5a	16.2a	92.1b	23.3a	44.5a
	Pearl	93.4a	14.0a	92.4b	23.6a	38.3b
	Red	82.6ab	15.1a	107.6a	21.9a	41.1ab

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

Figure 3.1. Transmittance percentage in different wavelengths of light under black (A), aluminet (B), pearl (C), and red (D) colored shade nets in different ornamental plants under greenhouse conditions in Stillwater, OK in 2021.



CHAPTER IV

COLORED SHADE NETS EFFECTS ON DAHLIAS AND SNAPDRAGON PLANTS UNDER GREENHOUSE AND FIELD CONDITIONS

Abstract

Colored shade nets are an emerging cropping technology, which can alter the intensity and spectrum of incident light for increased plant growth and quality. Two cultivars of snapdragon (*Antirrhinum majus* L.) and dahlias (*Dahlia pinnata* Cav.) were selected and grown in a greenhouse and at two different field locations. Aluminet, pearl, red, and black (control) shade nets with 50% shading intensity were used in this experiment. Several growth and quality measurements were conducted during the experiment and at the time of harvest. In the greenhouse, aluminet shade net performed best to increase all flowering and quality parameters in both crops except flower number in dahlias. With the field experiment, shade nets transmitting greater amounts of red light (aluminet, pearl, and red) performed best to increase growth and quality in snapdragon and dahlias. Red shade nets increased flower number and stem length for both crops in the field. Overall, aluminet colored shade net is recommended for greenhouse and red shade cloth is best for field conditions.

Introduction

Cut flowers are a major component of the floriculture industry, because of their use in decorations, and floral arrangements (Gaurav, 2014). There was an approximately 9% increase in wholesale floriculture sale between year 2019 and 2020 (USDA, 2021). Loyola et al. (2019) found that there is a huge increase in demand for local specialty cut flowers in the United States and Canada. Total wholesale value of cut flowers in the United States increased from 288 million in 2015 to 374 million in 2018 (USDA, 2019).

Different environmental factors such as temperature, light, and relative humidity are major concerns that can affect optimal growth and productivity of different ornamental crops grown in the field and greenhouse (Ntsoane et al., 2016). These alterations in turn affect growth and development aspects of plants. After light, temperature is the another major factor that controls growth and development in plants and high temperature due to intense solar radiation can cause various abiotic stresses in plants that deteriorate plant quality (Ilic et al., 2018).

To protect plants from intense solar radiation and extreme temperature conditions different types of shade nets are used (Al-Helal and Abdel-Ghany, 2010). Shade nets are either woven or knitted and vary in their texture, structure, design, and durability according to the material used (Shahak et al., 2004) In plants, light provides energy and helps to control photomorphogenesis, a process that controls several growth and developmental aspects (Teixeira, 2020). Shade nets are made from ultra-violet (UV) resistant plastic material which can scatter incoming light radiation and can change spectral properties of light (Shahak et al., 2008). Plants contain different photoreceptors that can sense spectral changes in light quality, direction, and duration (Teixeira, 2020). These nets help to control temperature extremes, restrict air movement, and protect plants from wind damage, and increase humidity near crop canopy which can be helpful to plants (Ilic et al., 2017). Shading can also protect plants from environmental hazards such as excessive heat, hail, birds, and insects (Stamps, 2009).

Plants grown in the shade have larger leaf areas because cells expand more to receive light for photosynthesis under low light intensities (Ilic et al., 2017). Similar results were found by

Ovadia et al. (2015) in which shading under red colored net produced longer branches with longer internodes in different cut flowers. In pansy (*Viola wittrockiana* L.), Austerman et al. (2022) found shade nets increase survival rate as compared to no shade treatment. Hernandez et al. (2020) found increased diameter and length of lisianthus (*Eustroma grandiflorun* L.) stems under red colored nets. Similarly, a study by Ovadia et al. (2015) found increased flower weight and branch length in different cut flower plants. Shahak et al. (2004) also found greater photosynthesis under red colored nets in apple (*Malus domestica* Borkh.) leaves. Bell pepper (*Capsicum annum* L.), ornamentals, and different leafy crops have shown increased productivity under red and pearl colored nets (Shahak et al., 2008). The objective of this study was to see if red colored shade net would help to increase growth and flowering of snapdragons and dahlias grown in a greenhouse or under field conditions as potted or cut flower plants, respectively.

Materials and methods

Location and greenhouse conditions. The research was conducted in 2021 and 2022. In 2021, a greenhouse experiment was conducted at the research greenhouse facility at Oklahoma State University, Stillwater campus (36.1361,-97.0863). No supplemental light was used in the greenhouse, daily light integral levels (DLI) averaged 17.2 ± 2.1 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. The average temperature was set at 21/18 °C in greenhouse and average temperature was 30.5 ± 1.2 °C. In 2022, field trials were located at Bear Creek farm in Stillwater, OK (36.0872,-97.0494) and a second location at Wild Lark farm in Claremore, OK (36.3109,-95.5761).

Plant material and treatments. During 2021, snapdragon ‘Rocket Pink’ and ‘Classic Bronze’ were obtained from Ball Horticulture (West Chicago, IL) in 288 cell trays along with tuberous roots of dahlia ‘Red Runner’. Tuberous roots of dahlia ‘Mystery Fox’ were obtained from Ednie Flower Bulb (Fredon, NJ). Both the snapdragon cultivars were received on 18 May 2021 and potted on 20 May 2021. Dahlias were received on 1 June 2021 and potted on 4 June 2021. All plants were transplanted into 15 cm pots filled with growing media (BM-7, 45% bark, Berger, Sulphur Springs, TX). Pots were spaced at 30 cm spacing. Polyvinyl chloride (PVC) pipes of 2.5 cm diameter were used to make frames of 0.762 m height to hold shade nets above the canopy. Shade net treatments included red, aluminet, pearl, and black as the control shade nets (Green-Tek, Janesville, WI) with 50% light intensity. Water was provided to plants as needed with drip irrigation pressure compensation using 2 gph drippers. A 15N-3.87P-10.44K (5-6 months) slow-release fertilizer (Osmococte Plus, Dublin, OH) was top dressed at 11 g per pot with 20% leaching fraction. Acetamiprid 8.5% (Tristar, Nufarm, Chicago, IL) was used to control mealybugs under greenhouse condition during summer 2021 at a rate of 7.5 ml per 3 gallons of water.

In 2022, seedling of snapdragon ‘Rocket Pink’ and ‘Classic Bronze’ were obtained from Ball Horticulture (West Chicago, IL) in 288 cell trays along with tuberous roots of dahlia ‘Red Runner’ and ‘Orange Pekoe’. Dahlias arrived on 21 April 2022 and were planted in the field at Bear Creek farm on 10 May 2022 and at Wild Lark farm on 17 May 2022. Snapdragons arrived on 23 May 2022 and were planted in field at Bear Creek farm on 30 May 2022 and at Wild Lark farm on 31 May 2022. Polyvinyl chloride (PVC) pipes of 2.5 cm diameter and 2 m long T-posts were used to make frames of 1.5 m height to hold shade nets above the canopy and extended along the sides. Shade net treatments included red, aluminet, pearl, and black as the control. shade nets (Green-Tek, Janesville, WI) with 50% light intensity. Water was provided to plants when required with drip irrigation system.

At Wild Lark farm, soil texture was loam with 50% sand, 32.5% silt, and 17.5% clay and soil pH was 7.8. At Bear Creek farm, the soil texture was a sandy loam with 52.5% sand, 32.5% silt, and 15% clay and soil pH was 6.6. At Wild Lark farm soil had 104 lbs./A nitrogen, 105 lbs./A phosphorous, and 305 lbs./A potassium content while at Beer Creek farm soil had 42 lbs./A nitrogen, 36 lbs./A phosphorous, and 149 lbs./A potassium content which was almost three times lower than Wild Lark farm. Data for temperature and relative humidity for Wild Lark farm was collected from Oklahoma Mesonet Skiatook Station which was 30 miles west of Wild Lark farm and for Bear Creek farm data was collected from Oklahoma Mesonet Stillwater Station which was 3 miles west of Bear Creek farm.

Data collection. In 2021, snapdragon plants were harvested after 10 weeks of transplanting on 28 July 2021, and dahlias were harvested after 13 weeks of transplanting on 16 September 2021. Data for plant height, flower number, stem length, chlorophyll concentrations, fresh weight and dry weight was collected. For dry weights, plant material was oven-dried for 2 d at 53.9 °C. Chlorophyll measurements (average of upper, middle, and base portion of a leaf) were made using a chlorophyll meter (Minolta SPAD-502, Spectrum Technologies, Haltom, TX). Carbon dioxide assimilation rate was measured 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 middle of the plant.Spectral data for reflectance was measured after 2 weeks of transplanting in the middle of the day using a reflectance spectrometer HL-2000- FHSA (Ocean Optics, Shanghai, China).

In 2022, data was collected for plant height, flower number, stem length, flower width, chlorophyll concentrations, and fresh weight and dry weight. Measurements of flower number, flower width, and stem length were conducted every week starting 8 weeks after transplanting, while measurements of plant height, chlorophyll concentration, shoot fresh weight, and shoot dry weight were made at time of harvesting. At Wild Lark farm plants were harvested on 30 September 2022 and at Beer Creek farm plants were harvested on 20 October 2022. Soil samples from Claremore and Stillwater and were sent to the soil, water, and forage analysis laboratory at Oklahoma State University for analysis. Analysis was done by using inductive coupled plasma mass spectrometry based on isotope analysis.

Statistical analysis. The experiment was set up as a randomized block design with 10 plants per treatment, and the experiment was replicated. For the end measure responses, mixed models' method was used since unequal variance was evident among the treatment levels. Tukey pairwise comparisons of significant effects were performed, all tests were conducted at the 0.05 level of significance and all data were analyzed using SAS 9.4 software.

Results for greenhouse experiment

Light intensity and quality, temperature and relative humidity

There were significant differences between different shade nets for DLI, temperature, and relative humidity (Table 4.1). Pearl showed the greatest DLI, while black and red resulted in the lowest DLI. Aluminet net had the lowest temperature, which contributed to relative humidity being greatest under aluminet and black nets. Black shade net had minimum reflectance with blue light nearly 30%, yellow and green up to 40%, and red light approximately 25% (Figure 2). Pearl shade net had reflection percentage ranging from 60 to 70% for all wavelengths of light, while aluminet shade net had 55% reflection for all wavelengths. Red shade net had 35% reflection percentage of blue, green, and yellow light while red light had 75 to 80% reflection percentage.

Shoot fresh weight showed a significant interaction between Cultivar × Treatment under different treatments for snapdragon cultivars (Table 4.2). 'Classic Bronze' showed the greatest shoot fresh weight under aluminet but was only different than black treatment (Table 4.3). 'Rocket Pink' showed greatest shoot fresh weight under aluminet which was not different from pearl treatment. Shoot dry weight, plant height, flower number, CO_2 assimilation rate, and chlorophyll concentration showed significant differences for treatment main effect (Table 4.2). Shoot dry weight, CO_2 assimilation rate, and chlorophyll concentration were greatest in aluminet (Table 4.4). Aluminet showed greatest plant height which was only different from pearl. Flower number was greatest under aluminet but was not different from pearl treatment. Shoot dry weight, plant height, and CO_2 assimilation rate showed differences among two snapdragon cultivars (Table 4.2). 'Classic

Bronze' showed greatest shoot dry weight, plant height, and CO_2 assimilation rate as compared to 'Rocket Pink' in snapdragon (Table 4.5).

In dahlias, significant differences for shoot fresh weight, shoot dry weight, flower number, CO_2 assimilation rate, and chlorophyll concentration were seen for treatment main effects (Table 2). Aluminet treatment showed the greatest shoot fresh weight, shoot dry weight, and chlorophyll concentration values which were different than black treatments (Table 4.4). Flower number was greatest in red treatment, while CO_2 assimilation rate was greatest in aluminet treatment.

Results for field experiment in summer 2022

Light quality, temperature, and relative humidity

Average temperature was 26 °C for Skiatook station and average relative humidity was 64.7% while at Stillwater station average temperature was 28 °C and average relative humidity was 83.7% (data not shown). The light reflection percentage data was combined for both Wild Lark and Bear Creek farms. Black colored showed 25 to 30% reflection of blue and red light while reflection of green and yellow light was 30 to 40% (Figure 2). Aluminet shade nets showed 50 to 55% reflection while pearl showed 60 to 70% reflection of blue to red light. Red shade nets showed 20% reflection of blue to yellow light while for red light reflection percentage was 90 to 100%.

Bear Creek Farm, Stillwater

Dahlias showed treatment main effects for shoot fresh weight, shoot dry weight, stem length, plant height, and chlorophyll concentration (Table 4.6). Shoot fresh weight was greatest under aluminet which was different than black while shoot dry weight was greatest under aluminet shade which was different than black and red (Table 4.7). Stem length was greatest under pearl which was not different than red while chlorophyll concentration was greatest under black and not different than aluminet and pearl (Table 4.7). Plant height was greatest under red nets which were not different than pearl. Cultivar main effects showed significant differences for shoot fresh weight, flower number, stem length, plant height, and chlorophyll concentration (Table 4.6). ‘Orange Pekoe’ showed greatest chlorophyll concentration while ‘Red Runner’ showed greatest shoot fresh weight (Table 4.8). ‘Orange Pekoe’ dahlias did not bloom. Snapdragon showed significant differences in main effects for shoot dry weight, flower number, plant height, and chlorophyll concentration (Table 4.6). Flower number was greatest under pearl which was not different than red while chlorophyll concentration was greatest under aluminet which was different from other treatments (Table 4.7). Shoot dry weight was greatest under aluminet which was not different than pearl. Plant height was greatest under red which was only different from black net. Stem length and shoot fresh weight, and shoot dry weight showed significant main effects for cultivar (Table 4.6). Stem length and shoot fresh weight was greatest in ‘Classic Bronze’ while shoot dry weight was greatest in ‘Rocket Pink’ (Table 4.8).

Wild Lark Farm, Claremore

Dahlias showed significant treatment main effects for shoot dry weight, plant height, flower number, stem length, and chlorophyll concentration (Table 4.9). Shoot dry weight was greatest under pearl which was different from red and stem length was greatest in pearl which was only different than black while plant height was greatest under red and not different from pearl (Table 4.10). Flower number was greatest under aluminet and not different from pearl and red while chlorophyll concentration was greatest under black which was different than red. Significant cultivar main effects were seen for shoot fresh weight, shoot dry weight, and chlorophyll concentration (Table 4.9). Shoot fresh and dry weight were greatest in ‘Red Runner’ and lowest were in ‘Orange Pekoe’. While chlorophyll concentration was greatest in ‘Orange Pekoe’ (Table 4.11).

Snapdragon showed significant treatment main effects for shoot dry weight, plant height, flower number, stem length, and chlorophyll concentration (Table 4.9). Flower number and stem length were greatest in red which were not different from pearl (Table 4.10). Chlorophyll concentrations and shoot dry weight were greatest under aluminet. Plant height was greatest under red which was not different from aluminet. Cultivar main effects were seen for shoot fresh weight, plant height, and chlorophyll concentration (Table 4.9). Shoot fresh weight, plant height, and chlorophyll concentration was greatest in 'Rocket Pink' while lowest in 'Classic Bronze' (Table 4.11).

Discussion

Chlorophyll concentrations were greatest under aluminet in both greenhouse and field conditions for both species, except dahlias at Bear Creek where black was greatest. Light is an important factor that determines the chlorophyll concentration. Chloroplasts can change their size according to changing light conditions and influence chlorophyll concentrations in leaves (Tanaka and Tanaka, 2006). Zare et al. (2019) found that chlorophyll concentrations started to decrease with high intensities of light but very low light intensities can also decrease chlorophyll concentrations. Yang et al. (2007) found that high air and canopy temperatures have detrimental effects on chlorophyll synthesis and lower temperature helps to increase chlorophyll synthesis. Ilic et al. (2017) showed greatest chlorophyll concentrations under black shade nets in sweet pepper (*Capsicum annum* L.). In our study, aluminet shade nets had the lowest temperature with moderate light intensities, which might explain increased concentration of chlorophyll under aluminet nets. Mditshwa et al. (2019) found that aluminet shade nets with 50% shading intensity helped to increase chlorophyll concentration in naval orange (*Citrus sinensis* L.) seedlings. During the field study, dahlias showed increased chlorophyll concentration under black shade nets, because temperatures and light intensities were lowest under black shade nets which were optimum for dahlia growth. Dahlias need medium light intensity and grow well with 12 to 16 mol· $m^{-2} \cdot d^{-1}$ of light (Torres and Lopez, 2012).

Shoot dry weight was greatest under aluminet in both snapdragon and dahlias in the greenhouse, snapdragon in the field, and dahlias at the Bear Creek Farm. Plants growth is directly dependent on photosynthetic activity and chlorophyll is a major component of the photosynthetic process. Angadi et al. (2022) found increased dry matter production of lima bean (*Phaseolus lunatus* L.) and pigeon pea (*Cajanus cajan* L.) under 30% aluminet shade nets. Pereira et al. (2011) also found that leaf dry weight and commercial yield of French melon (*Cucumis melo* L.) increased under aluminet shade nets compared to no shade and other chromatinets. The increased biomass may have been a result of increased chlorophyll concentration under aluminet. Liu et al. (2019) also found that that there is direct a relationship between chlorophyll concentration of leaves and above ground biomass.

Plant height in greenhouse conditions was greatest under aluminet shade in snapdragon but in the field trial plant height was greatest under red for both snapdragons and dahlias. Red light is known to help in stem elongation in plants because of absence of blue light (Mortensen and Stromme, 1987). Low blue/red light ratio might be the main reason of greater plant height in our experiment. In a study on grass lily (*Ornithogalum umbellatum* L.), Ovadia et al. (2015) found that plants under red shade nets had longer stems and internodal lengths. Gaurav et al. (2014) also found that red shade net helped to increase plant height by increasing internodal length in cordyline (*Cordyline terminalis* L.).

Flower number and stem length was greatest under aluminet, pearl, and red shade nets under different conditions. All these treatments had 50 to 90% reflection of red light under them while black had only 20 to 30%. Plants have different photoreceptors and red light is the most absorbed light by plant photoreceptors (Rajakapkse at al., 1999). Red light absorption and far-red light reflection under red shade affects the Red:Far-red (R:Fr) ratio that reaches plants, which in turn causes phytochromes to become inactive and led to stem elongation (Courbier and Pierik, 2019). Plants exposed to red shade have been shown to have greater levels of phytochrome interacting factor 5 (PIF 5) and PIF 4 as well as more auxin and fewer della proteins produced, which encourages stem elongation (Casal, 2012). This absorption of red light might be the reason to increase plant processes that can affect plant flowering and height. Ovadia et al. (2015) also found that red light helped to increase flower number and stem length in lisianthus (*Eustroma grandiflorum* L.) and throatwort (*Trachelium caeruleum* L.). Hernandez et al. (2008) also found that red colored shade nets had greatest stem length in lisianthus.

During the greenhouse experiment in 2021 red colored shade nets had greater levels of mealybug infestation on dahlia and snapdragon plants which was controlled by application of acetamiprid 8.5%. Ben-Yakir et al. (2012) found increased attack of aphids and whiteflies under red and black shade nets as compared to pearl and yellow colored shade nets. Similarly, Shahak et al. (2008) also found that black shade had increased attack of whiteflies compared to yellow shade nets. During the summer of 2022 plants under pearl shade net have noted as having greater amount of grasshoppers at Wild Lark Farmon them which were reduced after weeding.

Conclusion

In conclusion, this experiment is persistent with related finding that colored shade nets influence growth and quality in plants. Aluminet colored shade net is best to increase all growth and quality parameters in greenhouse conditions. During field conditions red, pearl, and aluminet colored shade nets are best to increase flowering in both crops. Shade nets can affect temperature and light quality which further affects physiological processes in plants and help to increase productivity and flowering. Further research could evaluate different shading percentages, cultivar, and species throughout the United States as light levels and temperature vary.

Table 4.1. Greenhouse conditions for daily light integral, temperature, and relative humidity under aluminet, black, pearl, and red colored shade nets in Stillwater, OK during summer 2021.

Treatment	Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)	Temperature (°C)	Relative humidity (%)
Aluminet	18.5b[z]	29.7c	64.9a
Black	12.4c	30.4b	63.8ab
Pearl	22.7a	30.6b	62.9b
Red	15.3c	31.3a	61.2c

[z]Within a column followed by same lowercase letter are not significantly different by pairwise comparison ($P \leq 0.05$).

Table 4.2. Summary ANOVA table for growth and quality parameters under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars under greenhouse conditions in Stillwater, OK during summer 2021.

Source	Cultivar	Treatment	Cultivar × Treatment	Source	Cultivar	Treatment	Cultivar × Treatment
	Snapdragon				Dahlias		
Shoot fresh weight	***[z]	***	***	Shoot fresh weight	NS[z]	*	NS
Shoot dry weight	***	***	NS	Shoot dry weight	NS	*	NS
Plant height	***	***	NS	Plant height	NS	NS	NS
Flower number	NS	***	NS	Flower number	NS	**	NS
Stem length	NS	NS	NS	Flower width	NS	NS	NS
CO_2 assimilation rate	***	*	NS	CO_2 assimilation rate	NS	***	NS
Chlorophyll concentration	NS	***	NS	Chlorophyll concentration	NS	*	NS

[z]Indicates significant at or non-significant (NS) at *$P \leq 0.05$, **$P \leq 0.01$, or ***$P \leq 0.001$.

Table 4.3. Cultivar × Treatment interaction for shoot fresh weight under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars under greenhouse conditions in Stillwater, OK during summer 2021.

Cultivar	Treatment	Shoot fresh weight (g)
Classic Bronze	Black	57.8bc[z]
	Aluminet	80.9a
	Pearl	68.9ab
	Red	70.1ab
Rocket Pink	Black	45.5c
	Aluminet	69.5ab
	Pearl	54.2bc
	Red	49.7c

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

Table 4.4. Main effects of treatment on shoot fresh weight, shoot dry weight, plant height, flower number, CO_2 assimilation rate, and chlorophyll concentration under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars under greenhouse conditions in Stillwater, OK during summer 2021.

Species	Treatment	Shoot fresh weight (g)	Shoot dry weight (g)	Plant height (cm)	Flower number	CO_2 assimilation rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Chlorophyll concentration (unitless)
Snapdragon	Black	51.7a[z]	7.8b	63.7ab	3.9c	18.1b	33.6b
	Aluminet	75.2a	10.7a	68.9a	6.7a	20.5a	35.5a
	Pearl	61.5b	8.9b	61.4b	5.8ab	17.9b	32.6b
	Red	59.9bc	8.2b	63.7ab	5.3b	17.6b	32.0b
Dahlias	Black	98.0b	12.1b	57.6a	4.1b	17.5b	5.2b
	Aluminet	107.3a	13.2a	62.4a	4.3b	20.5a	37.9a
	Pearl	104.0ab	12.8ab	60.4a	3.9b	16.4b	36.2ab
	Red	103.5ab	12.7ab	62.1a	6.1a	17.2b	35.7ab

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

Table 4.5. Main effects of cultivar on shoot dry weight, plant height, and CO_2 assimilation rate under aluminet, black, pearl, and red colored shade nets in snapdragon cultivars greenhouse conditions in Stillwater, OK during summer 2021.

Species	Treatment	Shoot dry weight (g)	Plant height (cm)	CO_2 assimilation rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$)
Snapdragon	Classic Bronze	9.5a[z]	77.4a	19.6a
	Rocket Pink	8.3b	51.5b	17.4b

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

Table 4.6. Summary ANOVA table for growth and quality parameters under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars in field conditions at Bear Creek Farm, Stillwater, OK during summer 2022.

Source	Cultivar	Treatment	Cultivar × Treatment	Source	Cultivar	Treatment	Cultivar × Treatment
	Snapdragon				Dahlias		
Shoot fresh weight	*[z]	NS	NS	Shoot fresh weight	**	*	NS
Shoot dry weight	**	***	NS	Shoot dry weight	NS	**	NS
Plant height	NS	***	NS	Plant height	*	**	NS
Flower number	NS	***	NS	Flower number	***	NS	NS
Stem length	*	NS	NS	Stem length	***	***	NS
Chlorophyll concentration	NS	***	NS	Chlorophyll concentration	**	*	NS
				Flower width	NS	NS	NS

[z] Indicates significant at or non-significant (NS) at $*P \leq 0.05$, $**P \leq 0.01$, or $***P \leq 0.001$.

Table 4.7. Main effects of treatment on shoot dry weight, plant height, chlorophyll concentration, flower number, and stem length under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars under greenhouse conditions at Bear Creek farm Stillwater, OK during summer 2022.

Species	Treatment	Shoot dry weight	Shoot fresh weight	Flower number	Stem length (cm)	Chlorophyll concentration (unitless)	Plant height (cm)
Snapdragon	Black	15.3c	160.3a	5.9c[z]	14.4a	46.6b	59.6b
	Aluminet	21.6a	183.2a	7.7b	18.0a	56.6a	65.3ab
	Pearl	19.3ab	175.3a	9.4a	16.1a	45.9b	67.4ab
	Red	18.2b	150.9a	9.0ab	16.6a	49.6b	75.9a
Dahlias	Black	30.2b	356.9b	4.2a	12.4b	45.5a	94.2b
	Aluminet	41.3a	433.6a	4.2a	11.7b	44.2ab	97.3b
	Pearl	38.2a	421.3a	5.1a	16.3a	43.9ab	101.9ab
	Red	31.2b	408.9ab	4.6a	15.2a	39.4b	107.6a

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

Table 4.8. Main effects of cultivar on flower number, stem length, and chlorophyll concentration under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars in field conditions at Beer Creek farm, Stillwater, OK during summer 2021.

Species	Treatment	Shoot fresh weight	Shoot dry weight	Flower number	Stem length (cm)	Chlorophyll concentration (unitless)
Snapdragon	Classic Bronze	136.9a	15.3b	7.5a	22.9a	50.1a
	Rocket Pink	156.3a	19.2a	8.4a	16.7b	49.1a
Dahlias	Orange Pekoe	369.2b	38.6a	-	-	45.5a
	Red Runner	422.3a	36.2a	7.7a	16.1a	40.9b

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

Table 4.9. Summary ANOVA table for growth and quality parameters under aluminet, black pearl, and red colored shade treatments in snapdragon and dahlia cultivars in field conditions at Wild Lark Farm, Claremore, OK during summer 2022.

Source	Cultivar	Treatment	Cultivar × Treatment	Source	Cultivar	Treatment	Cultivar × Treatment
	Snapdragon				Dahlias		
Shoot fresh weight	***[z]	NS	NS	Shoot fresh weight	***	NS	NS
Shoot dry weight	NS	*	NS	Shoot dry weight	***	*	NS
Plant height	***	***	NS	Plant height	NS	**	NS
Flower number	NS	***	NS	Flower number	NS	***	NS
Stem length	NS	**	NS	Stem length	NS	*	NS
Chlorophyll concentration	***	**	*	Chlorophyll concentration	**	*	NS
				Flower width	NS	NS	NS

[z]Indicates significant at or non-significant (NS) at $*P \leq 0.05$, $**P \leq 0.01$, or $***P \leq 0.001$.

Table 4.10. Main effects of treatment on shoot dry weight, plant height, chlorophyll concentration, flower number, and stem length under aluminet, black, pearl, and red colored shade nets in snapdragon and dahlia cultivars at Wild Lark farm Claremore, OK during summer 2022.

Species	Treatment	Shoot dry weight (g)	Plant height (cm)	Flower number	Stem length (cm)	Chlorophyll concentration (unitless)
Snapdragon	Black	19.3b[z]	62.5c	4.5b	15.8b	51.3b
	Aluminet	24.1a	75.7ab	5.2b	16.0b	61.3a
	Pearl	21.1a	68.1bc	7.3a	18.4a	50.1b
	Red	21.6a	78.6a	7.6a	18.6a	54.3b
Dahlias	Black	33.9ab	107.6b	2.0b	17.2b	50.2a
	Aluminet	36.4a	105.1b	8.5a	21.3ab	49.0ab
	Pearl	38.1a	120.0ab	6.7a	22.9a	48.6ab
	Red	31.8b	125.3a	6.7a	17.7ab	44.1b

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

Table 4.11. Main effects of cultivar on shoot fresh weight, shoot dry weight, plant height, and chlorophyll concentration under aluminet, black, pearl, and red colored shade nets in snapdragon cultivars greenhouse conditions in Wild Lark farm, Claremore, OK during summer 2021.

Species	Treatment	Shoot fresh weight	Shoot dry weight	Plant height (cm)	Chlorophyll concentration (unitless)
Snapdragon	Classic Bronze	125.0b	18.6a	63.0b	52.7b
	Rocket Pink	169.5a	14.5a	79.5a	55.9a
Dahlias	Orange Pekoe	227.05b	25.2b	115.0a	50.2a
	Red Runner	434.62a	45.5a	113.9a	45.7b

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

Figure 4.1. Reflection percentage in different wavelengths of light under black (A), aluminet (B), pearl (C), and red (D) colored shade nets in different ornamental plants under greenhouse conditions in Stillwater, OK in 2021.

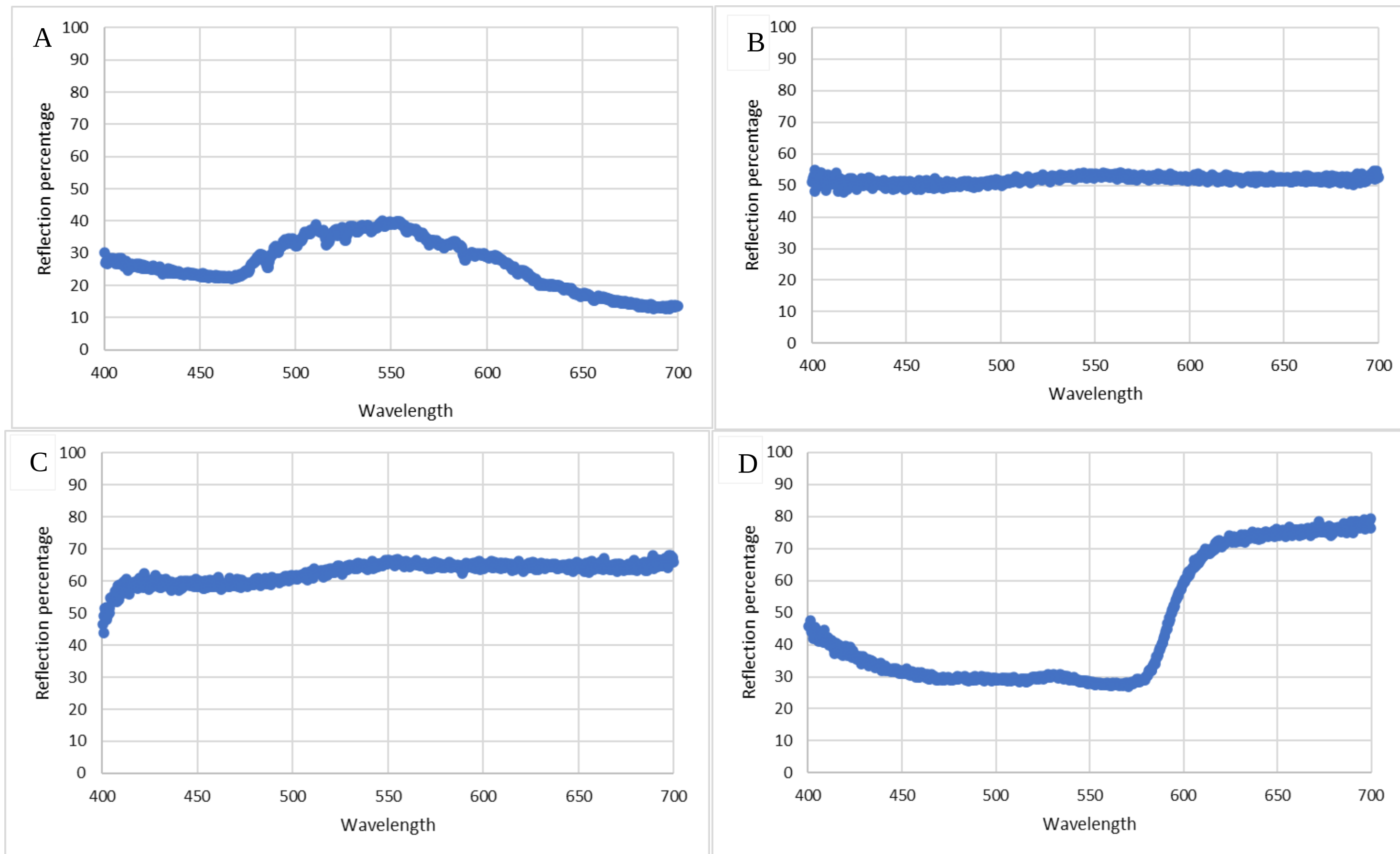
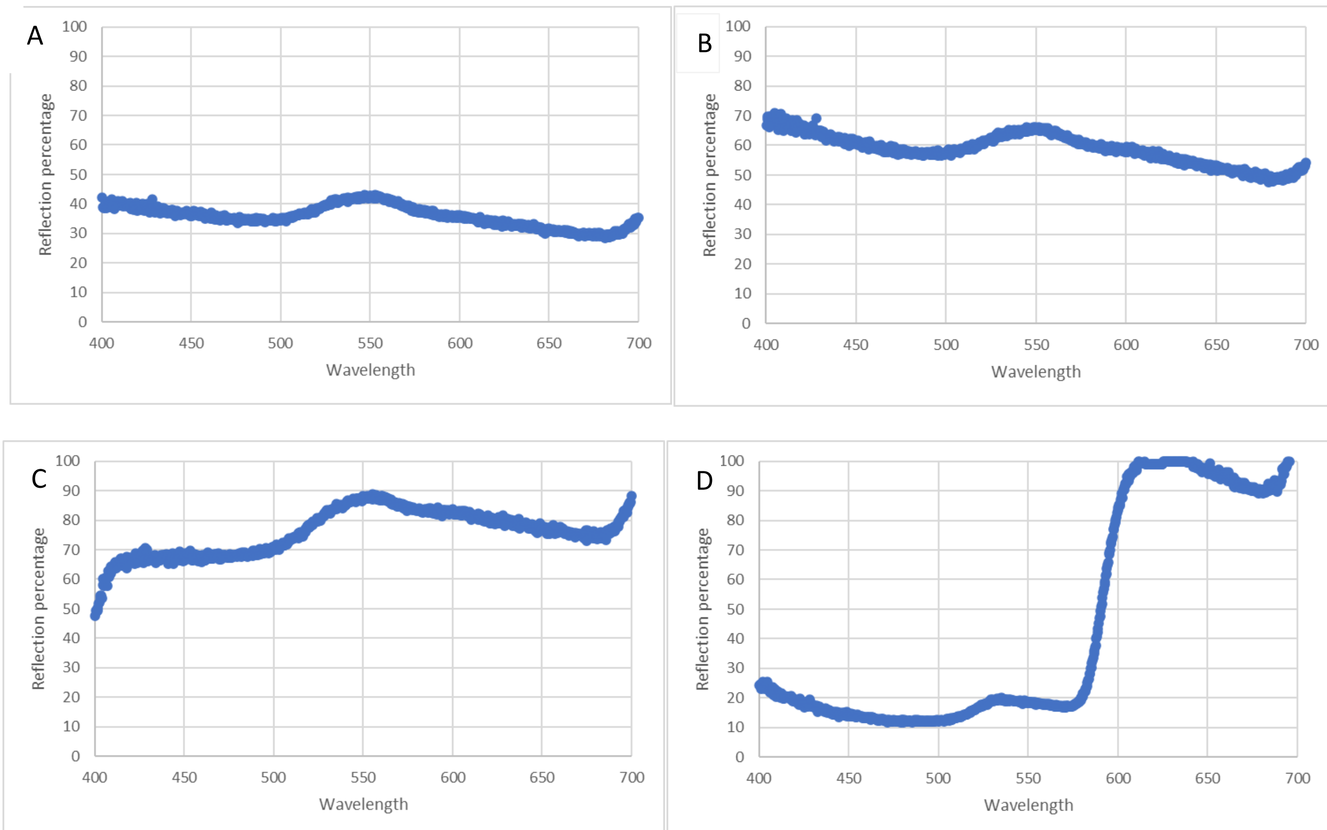


Figure 4.2. Reflection percentage in different wavelengths of light under black (A), aluminet (B), pearl (C), and red (D) colored shade nets in different ornamental plants in field conditions at Wild Lark and Beer Creek farms, OK in 2022.



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