EFFECTS OF CHROMATINET ON CUT SNAPDRAGONS AND SELECTED BEDDING AND VEGETABLE CROPS

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EFFECTS OF CHROMATINET ON CUT SNAPDRAGONS AND SELECTED

BEDDING AND VEGETABLE CROPS

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VITA

Charles Rembert McElhannon was born on March 20, 1982 in Athens, Georgia. He is the son of William and Carol McElhannon. He has two sisters, Catherine and Anna, and two brothers, Benjamin and Philip. Charles graduated from Cedar Shoals High School in 2000 and from the University of Georgia in 2005 with a Bachelors of Science in Agriculture. Charles married Laura Michelle Moore on June 17, 2006 and they are expecting their first child in October 2007. Charles began attending graduate school at Auburn University in August 2005 under Dr. J. Raymond Kessler, Associate Professor. He received his Master of Science degree in the summer of 2007.

THESIS ABSTRACT

EFFECTS OF CHROMATINET ON CUT SNAPDRAGONS AND SELECTED

BEDDING AND VEGETABLE CROPS

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The purpose of these studies was to evaluate the application of ChromatiNet as a growth modifying photoselective filter. The first study investigated three cultivars of snapdragon (*Antirrhinum majus*) as cut flowers in a high tunnel. The objective was to determine which ChromatiNet color would increase stem length because longer snapdragon stems receive a higher price in the marketplace. The snapdragons received four ChromatiNet colors (blue, grey, red, or pearl), black shade, or ambient light. The longest stems were under pearl and red ChromatiNet in 'Potomac Pink' and 'Potomac Royal' and under black shade in 'Potomac Yellow'.

While the first study was on cut flower stem elongation, subsequent studies were concentrated on producing more compact bedding plants. Commercial markets require growers of bedding plants to produce a product with uniform height that meets preset

specifications. In chapter three, four ChromatiNet colors (blue, grey, red, or pearl), black shade, or ambient light were used in two studies to investigate growth responses of bedding and vegetable plants, *Brassica oleracea*, *Capsicum annuum*, *Dianthus barbatus*, *Impatiens walleriana, Ipomoea tricolor, Lactuca sativa*, *Lycopersicon lycopersicum*, *Petunia floribunda*, *Salvia farinacea, Solenostemon scutellarioides, Viola cornuta, Viola* ×*wittrockiana*. In the first experiment, the shortest shoots were under ambient light and the tallest shoots were under red and pearl ChromatiNet. In general, grey ChromatiNet, black shade, and ambient light produced the most compact plants and red and pearl ChromatiNet produced the least compact plants. In the second experiment, the shortest shoots were under the black shade and grey ChromatiNet and tallest shoots were under pearl and red ChromatiNet and ambient light. Black shade consistently produced a smaller growth index and pearl ChromatiNet consistently produced a larger growth index.

In chapter four, *Antirrhinum majus, Ageratum houstonianum, Brassica oleracea*, *Celosia argentea, Dianthus barbatus, Ipomoea tricolor*, *Lycopersicon lycopersicum*, and *Viola* ×*wittrockiana* were used. In general, black shade produced the shortest plants and red and pearl ChromatiNet produced the tallest plants. However, no one treatment consistently maintained the shortest or the tallest plants from week to week. In general, black shade resulted in the smallest growth index and ambient light resulted in the largest. Black shade produced the lowest shoot dry weights in all species and ambient light produced the greatest shoot dry weights in all but one species, celosia. Further studies need to be conducted evaluating the effect of light intensity and the density of ChromatiNet on plant response.

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Style manual used

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CHAPTER I

LITERATURE REVIEW

In the ornamental horticulture industry, the regulation of stem extension and lateral plant growth is of extreme importance (5). Growers prefer uniform, compact plants because they are more desirable to consumers, easier to pack and ship, and increase the speed of transplanting (2). Uniform, compact plants can be difficult to achieve with close plant spacing because it often results in an uneven canopy of elongated, weak stems (3). Conventional plant growth retardants (PGRs) such as chlormequat, paclobutrazol, and daminozide have been used for decades to reduce vegetative growth and produce a higher quality crop (8). The trend is now toward finding alternative, non-chemical methods for producing compact plants to meet environmental concerns about chemical use and potential government restrictions on horticultural chemicals (2). Growers are also interested in growth control methods that reduce production cost (5). Currently, the USDA has not labeled any PGRs for vegetable crops (19) and stringent regulations exist for their use on ornamental crops (6). Greenhouse temperature manipulation, water and nutrient management, mechanical disturbance, and conventional breeding techniques are some of the alternatives that are currently being investigated for plant size control (2). Spectral filters have shown promising results as alternatives to PGRs (12).

Photomorphogenesis

Photomorphogenesis is a non-directional developmental response to a non-directional, non-periodic light stimulus in plants. Photomorphogenesis includes the ways in which light can regulate growth and development that are not included by the more specifically defined phenomena of phototropism and photoperiodism. This definition does not always receive universal acceptance because some researchers have used a much wider definition including photoperiodism and phototropism within the photomorphogenesis definition. Photomorphogenesis has been defined as, "the control which may be exerted by light over the growth, development, and differentiation of a plant, independently of photosynthesis" by Professor Hans Mohr of the University of Freiburg. This definition is too broad to be especially helpful, particularly when attempting to analyze the biological mechanisms underlying the processes of photomorphogenesis (24).

Photomorphogenic responses occur throughout the life of a plant. They are thought to be responsible for controlling stem elongation, leaf expansion, seed germination, phototropic and geotropic sensitivity, synthesis of chlorophyll, development of chloroplast structure, formation of stomata and leaf hairs, and synthesis of a wide range of secondary metabolites. Not all of these responses are regulated by light at the same time in any one species and several other responses are possible (24). It is important to note that photomorphogenesis responses are independent of photosynthesis (19).

The Fundamental Nature of Photomorphogenic Reactions

A basic sequence of events occurs when light is absorbed by a photoreceptive molecule and its chemical reactivity is thereby changed (24). The changed chemical reactivity in the photoreceptor initiates a sequence of metabolic processes that control physiological and morphological responses in the plant giving it the ability to sense subtle changes in light composition (19). To fully understand photomorphogenesis, information is required on the nature of the light stimulus, the chemical identity of the photoreceptor, the mechanism by which the photoreceptor trigger responses, the final nature of the changes, and the biochemical and molecular nature of the specific processes (24). Three classes of photoreceptors are known to detect light quality: phytochromes, cryptochromes, and at least one unidentified ultraviolet light receptor (20).

What is Phytochrome?

Phytochrome is the most rigorously studied photoreceptor (1) and is the primary pigment involved in photomorphogenesis (8). Phytochrome controls photomorphogenesis with changes from red (R) to far-red (FR) light in the growing environment (18, 19). Phytochrome can detect absorbance at red (600-700 nm), far-red (700-800 nm), and possibly blue (400-500 nm) wavelengths (20). There are two interconvertable forms of phytochrome: the active FR (P_{fr}) light absorption type and the inactive R (P_r) light absorption type. The P_r type has peak absorption around 660 nm and the P_{fr} type has peak absorption around 730 nm (8). Short lived intermediates also exist between the two forms (20). Many flowering plants use the R:FR ratio to determine flowering time based on the day and night length and to set circadian rhythms. Phytochrome regulates other plant responses including seed germination, seedling elongation, the size, shape, and number of leaves, chlorophyll synthesis, and straightening of the epicotyl or hypocotyl hook of dicotyledon seedlings. Phytochrome, biochemically, is a protein with a bilin chromophore. All higher plants were found to have phytochrome and similar molecules have been found in several bacteria. Other plant photoreceptors include phototropins and cryptochromes that are responsive to light in the blue and ultra-violet regions of the spectrum (24).

Photomorphogenesis and the Horticulture Industry

Natural sunlight at high noon produces R:FR ratio of 1.02 which can be manipulated to alter the growth of many plant species (10, 19). Reduced stem elongation of seedlings, enhancement of seed germination, and the promotion of lateral shoot growth are all physiological responses to R light exposure (19). These responses vary greatly by species (10). FR light is the polar opposite of R light in regulating plant growth. A growing environment high in R light relative to FR light promotes shorter internodes and denser foliage, thus producing compact plants. The desired ratio of R light to FR light can be obtained using supplemental electrical light systems that produce a high R:FR ratio or by using a spectral filter to change the R:FR balance. Incandescent lamps have a low R:FR ratio that can cause stem elongation, while fluorescent light sources have a high R:FR ratio that produces short, compact plants with heavy branching and short internodes (19).

Plant Responses to Liquid Spectral Filters

In the 1970s and 1980s, greenhouse filter systems, known as "fluid roof filters", were researched for filtering out infrared radiation as a method for cooling greenhouses (19). Aqueous dye filters have been investigated for removing FR light to decrease the stem elongation properties of natural sunlight (8). Liquid copper sulfate ($CuSO_4$) filters have shown much promise for plant height control (15).

Blue light produced by the CuSO4 solution in a "fluid roof system" was found to be effective in removing FR wavelengths, thus reducing plant height and increasing lateral bud breaks in chrysanthemum and tomato produced in a greenhouse (10). Green and yellow light were found to have the opposite effect by increasing plant height and inhibiting lateral breaks. Poinsettia and chrysanthemum cultivars grown under CuSO4 filters had reduced internode lengths and heights when compared with ambient light or water filter treatments (7, 9). In a study with 4%, 8%, and 16% CuSO4 filters on ‘Bright Golden Anne’ chrysanthemum, concentrations of 4% and 16% reduced photosynthetic photon flux by 26% and 47%, respectively. Regardless of concentration, internode length was reduced 35%; therefore 4% CuSO4 can be used effectively. The height reduction under CuSO4 filters occurred by decreasing internode length, not by decreasing the number of internodes. Plant quality under CuSO4 filters was the same as plants treated with chemical growth retardants, i.e. healthy dark green, compact stems (15).

A study using ‘Bright Golden Anne’ and 'Spears' chrysanthemum to determine if FR light reverses the CuSO4 filter induced height reduction found that exposure to FR light reversed the reduction of plant height, internode length, and shoot dry weight.

Plants grown under $CuSO_4$ filters used approximately 37% less water than controls. Yet, water loss rate per unit leaf area was similar to the control, suggesting that the reduction in water use was a result of the smaller plants produced by the $CuSO_4$ filters, not $CuSO_4$ filters themselves. When comparing control plants to plants grown under $CuSO_4$ filters, plants grown under filters had lower stomatal densities, though stomata size was not affected by any treatment. Plants grown under $CuSO_4$ filters had about 50% less total stomatal area when compared to the control, but this was due to reduced leaf area (18).

In a later study on chrysanthemum, dry weight per unit leaf area and per unit stem length were found to be reduced by light transmitted through $CuSO_4$ filters. Stem dry weight decreased while leaf dry weight increased. This implies that under $CuSO_4$ filters, translocation of photosynthates was altered (17).

Liquid $CuSO_4$ filters reduced the total amount of sucrose, glucose, fructose, and starch concentration in the stem and leaves of miniature roses and chrysanthemums. The reduction differed from growing season to growing season and was greater in the spring than in the fall. Under $CuSO_4$ filters, chrysanthemum leaf soluble salts were reduced by approximately 54% in the spring and 29% in the fall when compared to the controls. The reduction in available sugars could be from reduced photosynthetic area or an increase in plant respiration under $CuSO_4$ filters (16, 17).

The reduction in stored carbohydrates under $CuSO_4$ filters led to negative consequences on postharvest longevity. In miniature roses, postharvest quality was reduced and leaf chlorosis increased when plants were grown under $CuSO_4$ filters. Easter lilies were also negatively affected by $CuSO_4$ filters. Shelf life decreased by 3 to 4 days compared to control (19).

Physiological Basis of Light Quality Responses

Many physiological growth responses are controlled by gibberellins, a group of plant growth hormones involved in cell elongation, cell division, fruit set, and flowering. Gibberellins play a vital role in controlling stem elongation and internode length. The reduction in gibberellins by $CuSO_4$ filters is similar to the effect of PGRs. It is possible that $CuSO_4$ filters may affect biosynthesis of gibberellins or its activity may be similar to that of PGRs (19).

The biosynthesis of gibberellin is a complex process involving multiple enzymes as well as intermediate gibberellins. Current research is attempting to measure endogenous levels of gibberellins GA_{19}, GA_{20}, and GA_1, and analyze the various responses that spectral filters have on growth of chrysanthemums. Studies have shown that inactive GA_{19} concentrations are higher and active GA_1 levels are lower in plants grown under $CuSO_4$ filters. Plants grown under $CuSO_4$ filters had lower levels of exogenous GA_{19} than control plants. This study suggests that the transfiguration of GA_{19} to GA_{20} could be reduced by $CuSO_4$ filters thus limiting the amount of active GA within a plant (19).

Practical Use and Development of Photoselective Filters

Liquid $CuSO_4$ filters are effective in reducing stem elongation, but have never been embraced by the horticulture industry as a non-chemical control for growth because of their high cost of construction and the toxic nature of $CuSO_4$. Because of $CuSO_4$

filter limitations, a simple to use greenhouse covering material that would have the ability to filter out FR light needs to be developed. Several greenhouse covering producers, plastic companies, and chemical corporations have been trying to develop these materials (19).

Clemson University has collaborated with Mitsui Chemicals, Inc. (Tokyo, Japan) to develop a photoselective plastic greenhouse cover and rigid plastic panels. Mitsui Chemicals, Inc. identified two pigments that absorb FR light from sunlight and were stable in polyethylene films as well as rigid plastic panels. Initially, they tried to identify a stable dye as well as the proper concentration of the dye that would alter FR light from the natural light spectrum and reduce total plant height while minimizing a decrease in light transmission (19).

Mitsui Chemicals, Inc originally produced rigid plastic panels from each of five dyes. Growth chambers were constructed using each panel and growth of bell pepper, tomato, petunia, and watermelon seedlings and chrysanthemum cuttings were observed in each of the growth chambers. Each chamber was placed in the same greenhouse and light levels were adjusted inside the chambers with neutral density filters (1). The FR light absorbing panels decreased heights of all the species tested. The amount of height control differed among species. The greatest height reduction occurred in watermelon seedlings, followed by bell peppers, tomatoes, and chrysanthemums. The number of leaves was the same as the control plants showing that reduced heights were due to shorter internodes, not fewer internodes. As dye concentrations increased, plant height and dry weight decreased because light transmission was lower. It was found that dye concentrations with a light transmission of 75% would be useful for photoselective filters in future research (1).

In a later study on the rigid plastic panels, several ornamental flowering crops were also observed in the growth chambers with normal daylight controls. Cosmos, zinnia, and chrysanthemum (short day plants) showed a 1 to 2 day delay in flowering under the FR light absorbing panels. The FR absorbing panels had the greatest impact on the flowering of petunias and snapdragons (long day plants). These two species were delayed 7 to 13 days under the FR light absorbing panels (14). Petunias and snapdragons were possibly been in flowering by the lack of FR. Flowering of long day plants is promoted most when light contains both R and FR (20). The use of the R light absorbing film showed no significant effects on plant growth (14).

Current Concerns with Photoselective Films

A serious concern with Mitsui Chemicals, Inc. products is that the dye breaks down rapidly. Clemson University has experimented with full sun exposure as well as protected conditions in a greenhouse. The protected films lasted for over one year, but the dye in unprotected films broke down rapidly, after 10 months of exposure. This short life is a serious limitation in current research (19).

Applications of $CuSO_4$ filters are limited due to its toxic nature and high cost of production. Another concern is that the reduced light transmission from photoselective filters can limit their use in low light seasons. This can be a problem for northern growers with limited sunlight exposure (1).

ChromatiNet

Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) in collaboration with Yosepha Shahak and Michal Oren-Shamir of the Agricultural Research Organization (The Volcani Center, Bet-Dagan, Israel) has introduced plastic shade nets for use in modifying the light spectrum as an alternative to plastic film light regulation. These nets, known commercially as ColorNets or ChromatiNet, were designed to use special optical properties to improve the use of solar radiation received by crops. A series of shade nets was developed by the research team to modify the spectrum of filtered light, enhance the content of scattered light, and/or affect the thermal components of light in the infra-red region. ChromatiNet was designed to enhance desirable physiological responses such as yield, quality, and maturation rate. The nets offer varying mixes of natural, unmodified light and spectrally modified, diffused light depending on the pigmentation of the plastic and the density of the knitting design (21).

Polysack has introduced two types of shade nets: colored nets (blue, yellow, and red) that modify the visible light spectrum and non-colored nets (black, gray, and pearl) that modify the non-visible light spectrum and/or enhance light scattering (21). Yellow ChromatiNet is no longer sold by Polysack and black is currently sold as a shade net with shade percentages of 20-90% available. The nets are made of high-density polyethylene and are stable against UV radiation for 4 to 5 years, a significant advantage over the current plastic film technologies (13).

Blue ChromatiNet is available in 25 to 70% shade (13). It was shown to reduce the transmittance of R, FR, and UV spectrums and increase blue spectrum transmission

(22). Blue ChromatiNet was shown in dracaena to reduce leaf chlorophyll content when compared to standard black shade, possibly from a reduction in R light (4). Blue ChromatiNet inhibits stem elongation, reduces the number of branches, and shortens internode length (11). This creates a deeper green, more compact plant, allowing growers to grow larger quantities of plants using the same square footage. Blue ChromatiNet also has the potential to postpone flowering so that flowering time can be adjusted to meet market requirements (13).

Gray ChromatiNet is available in 25 to 80% shade. According to Polysack, it refracts light through its special crystalloid material which allows better light distribution (13). It creates a thermo-reflective barrier, absorbing infrared radiation and therefore creating a cooler microclimate (21, 22). Plants grown under gray ChromatiNet showed an increase in the number of shoots and buds and a noticeable increase in branching (11, 23).

Red ChromatiNet is available in shade densities of 25 to 70%. According to Polysack, it reduces the blue, green, and yellow light spectrums and increases the R and FR light spectrums. Plants have a larger and more leaves, healthier, darker green foliage, and longer, thicker stems. Polysack claims that red ChromatiNet produces higher quality, earlier flowering plants without decreasing flower quality (13). A 2000 study on pittosporum found that red ChromatiNet produced a stem elongation effect, although the study found no effect of the netting on blue light and only a minor effect on the R:FR ratio (11). In a 2006 study on ‘Janet Craig’ and ‘Colorama’ dracaena grown under 70% red ChromatiNet, plants were taller and fuller, but growers rated them low in quality due to their small leaf size. The larger plant was attributed to increased photosynthetically active radiation under the red ChromatiNet resulting in increased photosynthesis when compared to other treatments (4).

Pearl ChromatiNet is available in 30 to 60% shade and has the ability to scatter incoming light allowing the light to better penetrate the plant canopy, resulting in increased photosynthetic efficiency (22). This produces accelerated plant growth, increased number of secondary branches, and overall improved plant quality (13). Although not to the same extent, it should be noted that red, blue, and grey ChromatiNet scatter light. The scattering property of ChromatiNet allows plants to receive more overall light exposure than plants under the same density of black shade (22).

As public interest grows in using alternatives to PGRs, research will continue. As development of commercial photoselective filters for greenhouse production comes closer to reality, the nursery and greenhouse industry has a great opportunity to reduce costs of PGRs. The development of a commercial photoselective filter will reduce the risk growers take in exposing their workers to PGRs and the environmental impact of the horticulture industry (19).

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CHAPTER II

CHROMATINET EFFECTS ON STEM LENGTH AND DIAMETER OF SNAPDRAGONS GROWN AS CUT FLOWERS IN A HIGH TUNNEL

Abstract

The purpose of this study was to evaluate the application of ChromatiNet (CN) shade net in high tunnels for improving cut flower stem length and diameter of snapdragon (*Antirrhinum majus*). Three cultivars of snapdragons, ‘Potomac Pink’, ‘Potomac Royal’, and ‘Potomac Yellow’, were grown under blue, grey, red, or pearl CN and black shade at 30% density or ambient light in a high tunnel. Inflorescence length and stem fresh weights were not affected by treatments. Red and pearl CN produced the longest stems in ‘Potomac Pink’ and ‘Potomac Royal’; however they were similar to black shade and ambient light in ‘Potomac Pink’. Black shade produced the longest stems in ‘Potomac Yellow’, but was similar to blue, red, and pearl CN. The largest stem diameters were produced under black shade and gray CN in ‘Potomac Pink’, black shade and blue CN in ‘Potomac Royal’, and blue, red, and pearl CN and ambient light in ‘Potomac Yellow’. However, stem diameters of black shade and grey CN were similar to blue CN in ‘Potomac Pink’. There were no consistent stem length or stem diameter responses among the three cultivars in comparing cultivar differences within treatments.

Index words: spectral filter, growth modification, photoselective filter, colored shade cloth.

Species used in this study: 'Potomac Pink', 'Potomac Royal', and 'Potomac Yellow' snapdragon (*Antirrhinum majus* L.).

Significance to Industry

Snapdragon (*Antirrhinum majus*) cultivars are graded on stem length, stem weight, and number of open florets. A longer stem length receives a higher rating and thus can sell for a greater price. The use of ChromatiNet (a spectral filter) is a viable means for increasing stem length. This study showed that snapdragon cut flower production using red or pearl ChromatiNet can be used to successfully increase stem length.

Introduction

A high tunnel is a simple, non-permanent, greenhouse-like structure (4). High tunnels cost less to purchase and construct than traditional greenhouse systems, but provide adequate protection from environmental stresses such as wind, rain, low temperatures, weeds, and some disease and insect control (13). High tunnels provide many benefits such as decreasing the time needed to produce a marketable crop and allowing farmers to diversify farming operations (4). They provide a longer market window by extending the cropping season and thus are used for high value crops (3, 13).

In southern Europe, Asia, and the Middle East, high tunnels are used for growing vegetable crops, cut flowers, and many ornamental crops (13, 14).

Cut flower snapdragons are a popular crop with retail florists and have much potential for commercial importance in the southeastern U.S. They can be grown in most areas of the country (9) and are ideally suited for local high tunnel production (7). Snapdragons are placed into four groups based on optimum response to growing conditions (1). Group I cultivars are grown in winter and early spring, Group II cultivars in late winter and spring, Group III cultivars in late spring and fall, and Group IV cultivars in summer. Group I cultivars should not be grown in the southeast due to cold temperature requirements not found in that climate. In the south, Group II cultivars flower from December 15 to April 1, Group III from April 1 to June 1 and from November 1 to December 15, and Group IV from June 1 to November 1 (1, 7). High tunnel produced snapdragons have the potential to be higher in quality than field grown snapdragons. These snapdragons had less environmental damage due to the protective nature of the high tunnel, thus producing a higher quality crop with less physical damage to flowers, leaves, and stems (4).

Stem length is of vital importance to cut snapdragon production. Standard grades for snapdragon quality have been established by the Society of American Florists. Growers must meet the minimum specifications within each grade to sell at the market grade price. Snapdragon grading is based on stem length, stem weight, and number of open florets. A greater stem length receives a higher rating and thus can sell for a greater price (7).

There have been many attempts in the horticulture industry to change plant height by altering environmental conditions including fertility, watering regiments, mechanical disturbance, and temperature. They can be effective, but unfortunately using environmental controls has not constantly produced a consistent product (8). Proper temperature manipulation in the south can be difficult during the summer seasons, while light can be manipulated with specialized filters that can provide different physiological responses.

Spectral filters have been used experimentally to control plant height. However, much of the research has focused on reducing height, but the opposite is desired in snapdragon production (8). A method for increasing snapdragon height while maintaining product consistency and quality would be beneficial.

Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) in collaboration with the Agricultural Research Organization (The Volcani Center, Bet-Dagan, Israel) has introduced plastic shade nets for use in modifying the ambient light spectrum. These nets, known as ChromatiNet, were designed to use special optical properties to improve the use of solar radiation received by crops. A series of shade nets was developed by the research team to modify the spectrum of filtered light, enhance the content of scattered light, and/or affect the thermal components of light in the infrared region. ChromatiNet is designed to enhance desirable physiological responses such as yield, quality, and maturation rate. The nets offer varying mixes of natural, unmodified light and spectrally modified, diffused light depending on the pigmentation of the plastic and the density of the knitting design (10).

Blue ChromatiNet was shown to reduce the transmittance of red light (R), far-red light (FR) and ultraviolet light (UV) spectrums and increase blue spectrum transmission (11). Blue ChromatiNet inhibits stem elongation, reduces the number of branches, and shortens internode length. While these qualities are undesirable in cut snapdragon production, blue ChromatiNet does have the potential to postpone flowering so that flowering time can be adjusted to meet market requirements (5, 6).

According to Polysack, grey ChromatiNet refracts light through its special crystalloid material which allows for better light distribution (6). It provides a thermo-reflective barrier, absorbing infrared radiation and therefore creates a cooler microclimate (11, 12). Plants grown under grey ChromatiNet have an increased number of shoots, buds, and branches (5, 12).

Red ChromatiNet reduces the spectrum of blue, green, and yellow light and increases the R and FR light spectrum. This produces plants with larger and more leaves, healthier, darker green foliage, and longer, thicker stems. Polysack claims that red ChromatiNet produces higher quality, earlier flowering plants without decreasing flower quality (6). A 2000 study with pittosporum found that red ChromatiNet produced a stem elongation effect (5). A 2006 study using 70% ChromatiNet on 'Janet Craig' and 'Colorama' dracaena found that red produced a taller, fuller plant, but grower evaluations rated them low in quality due to small leaf size. The larger plant was attributed to increased photosynthetically active radiation under the red ChromatiNet resulting in increased photosynthesis when compared to other treatments (2).

Pearl ChromatiNet scatters incoming light so light better penetrates the plant canopy, resulting in increased photosynthetic efficiency (11). This accelerates plant growth, increases the number of secondary branches, and overall improves plant quality (6). Although not to the same extent, red, blue, and grey ChromatiNet scatter light. The scattering property of ChromatiNet provides plants more overall light exposure than those under the same black shade density (11).

The objective of this study was to determine the effects of several colors of ChromatiNet on growth of three snapdragon (*Antirrhinum majus*) cultivars produced in a high tunnel.

Materials and Methods

The experiment was conducted in the spring of 2006 at the Auburn University, E.V. Smith Research Center (Shorter, AL). A high tunnel (Clear Span Poly Shelters, Lutherville, MD) was constructed with dimensions of 29.2×7.92×3.65 m (96×26×12 ft). The high tunnel was positioned on an east/west longitudinal axis and was covered with a single layer of 0.15 mm (6-mil) polyethylene plastic. Wiggle wire lock was attached 1.21 m (4 ft) above the base to allow for rollup sides. The sides were rolled down when strong winds were expected. Otherwise, the sides were rolled up to allow for passive cooling. A triple zipper panel was attached to both ends and was only opened to facilitate equipment entry.

Raised beds 46 cm (18 in) wide, 26.8 m (88 ft) long, and 20.3 cm (8 in) tall were constructed 40.6 cm (16 in) apart using a mulch bedder (Reddick Fumigants, Wilmington, NC). Each bed had a single line of T-Tape® in the center that delivered 1.7

Lpm/30.5 m (0.45 gpm/100 ft) (T-Systems International, San Diego, CA). A soil test by the Auburn University Soil Testing Laboratory (Auburn, AL) indicated that the 6.9 pH was optimal and that nutrient levels were medium to high. Therefore, no lime or pre-plant fertilizer was applied.

Seedlings of 'Potomac Pink', 'Potomac Royal', and 'Potomac Yellow' (Group III) snapdragons were provided by Ball Seed Company (West Chicago, IL) in 288 plug flats. The seedlings were planted on raised beds in two rows with spacing between rows of 20.2 cm (8 in) and spacing within rows of 15.2 cm (6 in) on April 7, 2006.

Netting support structures were placed over the beds after planting. Fifteen support structures, 183×244×122 cm (72×96×48 in) in size, were constructed of 1.9 cm (0.75 in) Schedule 40 PVC. ChromatiNet (CN) was placed in a single layer on top of each structure and attached with 20 cm (8 in) cable ties at the base of each structure allowing the netting to drape over the top and around the sides. Two 45 cm (18 in) landscaping stakes were driven into the soil on either side of the structures and attached to the structures with cable ties to ensure that they did not blow over in the wind. The structures were oriented length wise over the rows.

The plants were watered daily. Liquid fertilizer at 250 ppm N from a 15N-4.4P-17.6K (20-10-20 Pro-Sol ™, Ozark, AL) was applied every third watering through the T-Tape® until the soil was saturated. Uniform irrigation conditions were difficult to achieve. Plants were exposed to excess field flooding during hurricane season and drought conditions when consistent irrigation was not maintained.

Poast herbicide (18 % sethoxydim, BASF Corp., Research Triangle Park, NC) was applied at 4 and 6 weeks after planting, between rows and under the structures at 15 ml /3 l (0.64 oz/gal) of water with 5 ml (0.17 oz) of crop oil concentrate (Ag Concepts Corp., Boise, ID) through a CO_2 backpack sprayer for grass weed control. Intermittent sprays of Gly Star Original (41% glyphosate, Albaugh, Ankeny, IA) were used to control other weeds between rows and under structures at a 5% concentration as needed.

Snapdragons were harvested when approximately half of the subplot inflorescences were three quarters open. The entire subplot was harvested at once. Stems were cut at the soil line, bundled into subplot bunches of 18, tagged, placed in 151 L (40 gal) trash cans containing tap water and placed in a walk-in cooler (Kolpak, Brooklyn, NY) at 3.9 C (39 F) for 24 hours. Total stem length and stem diameter 2.54 cm (1 in) below the inflorescence, inflorescence length, and inflorescence fresh weight were recorded. High winds near harvest times damaged the inflorescences of most plants so time to flower and visual quality ratings were not recorded.

The three cultivars were exposed to blue, grey, red, and pearl CN and black shade at 30% density. Each treatment was replicated three times with three controls in ambient light conditions. Treatments were assigned at the time of planting. The three cultivars were replicated twice within each structure. Within each plot were a total of six subplots with 16 plants per subplot. The experiment was a split-plot design with shade treatments as the main plot and snapdragon cultivar as the sub-plot; sub-samples within each sub-plot were treated as repeated measurements. The PROC-MIXED procedure in PC-SAS (SAS Institute, Cary, NC) was used to determine the significance of main effects and interactions, $P = 0.05$. Treatment differences were determined using the Bonferroni Multiple Range Test, $P = 0.05$.

Results and Discussion

There was no effect of shade treatments on inflorescence length or fresh weight. The interaction of cultivar and shade treatments was significant for stem length (Table 1). 'Potomac Pink' had longer stems grown under either red or pearl CN than those grown under blue or grey CN. However, stems of all were similar to black shade and ambient light. Stems were about 20% longer under red and pearl CN than those under blue and grey CN. 'Potomac Royal' grown under either red or pearl CN had longer stems than those under black shade, blue and grey CN, and ambient light. Stems were about 19% longer under red and pearl CN than those under black shade, blue and grey CN, and ambient light. 'Potomac Yellow' grown under black shade had longer stems than those grown under grey CN and ambient light. However, stems of black shade were similar to blue, red, and pearl CN. Stems were 19 % and 29% longer under black shade than those under grey CN and ambient light, respectively.

When comparing cultivar stem length differences within shade treatments, there was no consistent response among the three cultivars (Table 1). Black shade and blue CN yielded shorter stems in 'Potomac Pink' and 'Potomac Royal' than in 'Potomac Yellow'. 'Potomac Pink' and 'Potomac Yellow' had shorter stems under grey CN, red CN, and ambient light than 'Potomac Royal', while 'Potomac Pink' and 'Potomac Royal' had longer stems under pearl netting than 'Potomac Yellow'.

The interaction of cultivar and treatments was significant for stem diameter (Table 1). ‘Potomac Pink’ grown under either black shade or grey CN had larger diameters than those grown under red and pearl CN or ambient light. However, diameters of black shade and grey CN were similar to blue CN. Stem diameters were 21%, 14% and 14% larger under black shade and 26%, 20%, and 20% larger under grey CN, than those grown under red and pearl CN and ambient light, respectively. Either black shade or blue CN produced the largest diameters in ‘Potomac Royal’ and grey CN produced the smallest. Stem diameters were 50% larger under black shade and blue CN than those under grey CN and 28% larger under black shade and blue CN than those under red and pearl CN and ambient light. ‘Potomac Yellow’ grown under blue, red, and pearl CN and ambient light had larger stem diameters than those under black shade and grey CN. Stem diameters were about 15% larger under blue, red, and pearl CN and ambient light than those under black shade and grey CN.

There was no consistent stem diameter response among the three cultivars in comparing cultivar differences within treatments (Table 1). Stem diameters under black shade were the larger in ‘Potomac Pink’ and ‘Potomac Royal’ than in ‘Potomac Yellow’. Stem diameters of all three cultivars were similar under blue CN. ‘Potomac Pink’ stem diameters were largest under grey CN followed by ‘Potomac Yellow’ and then ‘Potomac Royal’. ‘Potomac Pink’ and ‘Potomac Royal’ had smaller stem diameters than ‘Potomac Yellow’ under red and pearl CN. ‘Potomac Pink’ and ‘Potomac Yellow’ had larger stem diameters under ambient light than ‘Potomac Royal’.

In general, red and pearl CN produced the longest stems in ‘Potomac Pink’ and ‘Potomac Royal’. However, black shade produced the longest stems in ‘Potomac Yellow’ which was unexpected. The stem elongation effect of red and pearl CN was to be expected based on manufacture’s claims and previous research. Previous studies have shown that red CN produced taller plants than black shade control (2, 6). Red CN likely resulted in a stem elongation effect due to the increase of R and FR light spectrums (2, 5). The light scattering properties of pearl CN allowed better light penetration into the plant canopy resulting in an increase in photosynthetic efficiency (11). This could have possibly accelerated plant growth in ‘Potomac Pink’ and ‘Potomac Royal’ resulting in longer stem lengths (6). Stem lengths in ‘Potomac Yellow’ can not be explained by the current literature.

There was no correlation between stem length and stem diameter and no consistent stem diameter response among the three cultivars. Based on manufacturer claims, the red CN should have resulted thicker stems (6), however this was only the case in ‘Potomac Yellow’. Although cultivar growth requirements are the same, perhaps subtle genetic differences or flooding and drought conditions attributed to these results. In cut flower production of snapdragons, longer stem length receives a greater price, so using red and pearl CN in production should generally yield a better quality cut flower that commands a higher price.

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Table 1. Effect of ChromatiNet, black shade, and ambient light on three snapdragon cultivars grown in a high tunnel.[z]

Shade	'Potomac Pink'	'Potomac Royal'	'Potomac Yellow'
	Stem length (cm)		
Black	72.2[y]ab B[x]	73.1b B	87.6a A
Blue	68.6b B	73.4b B	80.3ab A
Grey	66.7b B	74.4b A	73.9b B
Red	81.7a B	88.3a A	82.1ab B
Pearl	80.7a A	86.9a A	80.3ab B
Ambient light	71.7ab B	73.5b A	68.0c B
	Stem diameter (mm)		
Black	6.4a A	6.7a A	5.2b B
Blue	6.2abA	6.5aA	6.1aA
Grey	6.7a A	4.4c C	5.3b B
Red	5.3c B	5.2b B	6.0a A
Pearl	5.6bc B	5.2b B	6.1a A
Ambient light	5.6bc A	5.1b B	6.0a A

[z]There was an interaction between cultivar and ChromatiNet color, *P* = 0.05.
[y]Least squares means.
[x]Mean separation in columns (lower case) and rows (upper case) using the Bonferroni Multiple Range Test, *P* = 0.05.

CHAPTER III

THE EFFECTS OF CHROMATINET ON GREENHOUSE CROPS

Abstract

Four ChromatiNet (CN) colors, photoselective filters produced by Polysack, were used to determine growth responses of bedding and vegetable plants (*Brassica oleracea* 'Patron', *Brassica oleracea* 'Blue Vantage', *Brassica oleracea* 'Kale Peacock Red', *Capsicum annuum* 'Sweet X3R Camelot Hybrid', *Dianthus barbatus* 'Dynasty Red' , *Impatiens walleriana* 'Envoy Peach Butterfly', *Ipomoea amnicola* ' Crimson Rambler', *Lactuca sativa* 'Esmeralda', *Lycopersicon lycopersicum* 'Sun Leaper', *Petunia floribunda* ' Celebrity Red', *Salvia farinacea* 'Victoria Blue', *Solenostemon scutellarioides* 'Wizard Violet Red', *Viola cornuta* 'Orange', *Viola ×wittrockiana* 'Delta White Blotch') in a greenhouse in Auburn, AL. In the first experiment, the shortest shoots were under ambient light conditions while the tallest shoots were under red and pearl CN. In general, grey CN, black shade, and ambient light produced the most compact plants while red and pearl CN produced the least compact plants. Blue CN generally produced the best color ratings and pearl CN and ambient light produced the worst foliage color ratings. In the second experiment, the shortest shoots were under the black shade and grey CN and the tallest under pearl and red CN and ambient light. Black shade was the

most consistent in producing a small growth index and pearl CN was most consistent at producing a large growth index.

Index words: spectral filter, photoselective filter, growth modification, chemical growth retardants alternatives.

Species used in this study: broccoli (*Brassica oleracea* L. ‘Patron’), cabbage (*Brassica oleracea* L. ‘Blue Vantage’), kale (*Brassica oleracea* L. ‘Kale Peacock Red’), pepper (*Capsicum annuum* L. ‘Sweet X3R Camelot Hybrid’), dianthus (*Dianthus barbatus* L. ‘Dynasty Red’), impatiens (*Impatiens walleriana* Hook f. ‘Envoy Peach Butterfly’), morning glory (*Ipomoea tricolor* Cav. ‘Crimson Rambler’), lettuce (*Lactuca sativa* L. ‘Esmeralda’), tomato (*Lycopersicon lycopersicum* L. ‘Sun Leaper’), petunia (*Petunia floribunda* Juss. ‘Celebrity Red’), mealycup sage (*Salvia farinacea* Benth. ‘Victoria Blue’), coleus (*Solenostemon scutellarioides* L. ‘Wizard Violet Red’), viola (*Viola cornuta* L. ‘Orange’), pansy (*Viola ×wittrockiana* Gams. ‘Delta White Blotch’)

Significance to the Nursery Industry

The ability to modify plant growth and control appearance is critical to the marketability of greenhouse produced crops. The use of ChromatiNet (a spectral filter) is a potential means for modifying plant growth. This study shows that ChromatiNet can be used to modify growth of greenhouse produced crops; however ChromatiNet color must be properly selected for individual species to achieve the desired plant compactness effects.

Introduction

In the commercial greenhouse industry, the ability to control plant height is of extreme importance (8). Buyers are becoming quite specific on the exact size of plants purchased and proper regulation of stem extension and lateral plant growth can increase the market value (1, 3). Growers prefer uniform, compact plants because they are more desirable to consumers, easier to pack and ship, and quicker to transplant (1). Uniform, compact plants can be difficult to achieve with close plant spacing because it often results in an uneven canopy of elongated weak stems (2).

Current methods for controlling plant height include altering environmental conditions such as fertility, watering regiments, and temperature and the application of plant growth retardants (PGRs) that inhibit the biosynthesis of gibberellin (1, 9). PGRs can be effective at reducing unwanted growth without decreasing plant quality, but their use can add a considerable cost to crop production and the restrictions on their usage have been tightened (1, 7). Non-chemical environmental control methods are desired to meet environmental concerns of chemical use and potential government restrictions on horticultural chemicals. They can be effective, but unfortunately using environmental controls has not produced a consistent product (1).

An alternative method to control plant growth uniformly and consistently would be beneficial. Manipulation of the red (R) and far-red (FR) light spectrum can alter the growth of many plant species (5). A growing environment with a high R:FR ratio favors production of short, compact plants (8).

Many materials, known as spectral filters, have been used experimentally to increase the R:FR ratio (9). The use of copper sulfate ($CuSO_4$) filters to reduce FR wavelengths was found to be an effective non-chemical growth retardant (4, 8). Unfortunately, the toxic nature of CuSO4 and the high cost of construction were prohibitive to its use in the horticulture industry. Recently, Clemson University has collaborated with Mitsui Chemicals, Inc. (Tokyo, Japan), to produce a photoselective plastic greenhouse cover and rigid plastic panels to control plant height. They identified two pigments that absorb FR light from sunlight and were stable in polyethylene films as well as the rigid plastic panels. In research, the new filters have been able to reduce growth of several plant species. However, these new filters are not currently available to U.S. growers and the dye used to manufacture the filters breaks down rapidly which is a serious limitation in current research (8).

Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) in collaboration with the Agricultural Research Organization (The Volcani Center, Bet-Dagan, Israel) has introduced plastic shade nets for use in modifying the ambient light spectrum. A series of shade nets was developed by the research team to modify the spectrum of filtered light, enhance the content of scattered light, and/or affect the thermal components of light in the infrared region. ChromatiNet is designed to enhance desirable physiological responses such as yield, quality, and maturation rate. The nets are made of high-density polyethylene and are stable against UV rays for 4 to 5 years (6). The nets offer varying mixes of natural, unmodified light and spectrally modified, diffused light depending on the pigmentation of the plastic and the density of the knitting design (10).

Blue ChromatiNet was shown to reduce the transmittance of R, FR, and UV spectrums and increase blue spectrum transmission (11). Blue ChromatiNet inhibits stem elongation, reduces branching, shortens internode length, and has the potential to postpone flowering so that flowering time can be adjusted to meet market requirements (5, 6).

According to Polysack, grey ChromatiNet refracts light through its special crystalloid material that allows for better light distribution (6). It creates a thermo-reflective barrier, absorbing infrared radiation and therefore creating a cooler microclimate (11, 12). Plants grown under grey ChromatiNet have an increase in the number of shoots and buds and a noticeable increase in branching (5, 12).

Red ChromatiNet reduces the spectrum of blue, green, and yellow light and increases the R and FR light spectrum. This created plants with a larger surface area, healthier, darker green foliage, and longer, thicker stems. Polysack claims that red ChromatiNet produces higher quality, earlier flowering plants without decreasing flower quality (6).

Pearl ChromatiNet has the ability to scatter incoming light allowing the light to better penetrate the plant canopy, resulting in increased photosynthetic efficiency (11). This produces accelerated plant growth, increased the number of secondary branches, and overall improved plant quality (6).

The objective of this study was to determine the effects of several ChromatiNet colors on the growth of bedding and vegetable plant species grown in a greenhouse environment.

Materials and Methods

Experiment one. The experiment was conducted beginning September 1, 2006 at the Auburn University Greenhouse Facility (Auburn, AL). Seedlings of *Brassica oleracea* ‘Kale Peacock Red’, *Impatiens walleriana* ‘Envoy peach Butterfly’, *Petunia floribunda* ‘Celebrity Red’, *Salvia farinacea* ‘Victoria Blue’, *Solenostemon scutellarioides* ‘Wizard Violet Red’, and *Viola ×wittrockiana* ‘Delta White Blotch’ were provided by Young's Plant Farm (Auburn, AL), in 196-cell flats. The plugs were planted into LE 606 super jumbo packs 167.25 cm^3 (10.21 in^3) per cell filled with Fafard 3B Mix (Fafard, Anderson, SC). Plants were placed on metal benches in an unshaded greenhouse with a heat set point of 18.3C (65F) and ventilation beginning at 25.5C (78F). The greenhouse was covered with 8 mm (0.32 in) twin-wall polycarbonate.

Fifteen netting support structures, 162×112×45 cm (63.8×44.1×17.6 in) in size, were constructed of 1.9 cm (0.75 in) SCH 40 PVC. ChromatiNet shade net (CN) in blue, grey, red, or pearl or black shade (Polysack Plastic Industries, Ltd., Nir-Yitzhak, Sufa, Israel) was placed in a single layer on top of each structure and attached with 20.3 cm (8 in) cable ties at the base of each structure allowing the netting to drape over the top and around the sides to the bench surface. Support structures were placed over the plants after planting.

The plants were fertilized from planting with a 10.5N-1.76P-12.32K (14-4-14 CAL-P-MAG, Total Gro. TM, Winnsboro, LA), applied at a rate of 150 ppm N through a

Dosatron (Tresses, France) injector. Fertilizer was applied three out of every four waterings.

Foliage color ratings and plant compactness ratings were taken two weeks after treatments began. These ratings were evaluated by visual observation and rated on a 1 to 3 scale with 1 being the best rating and 3 being the worst. Shoot height and widths were recorded to calculate growth index (height + widest width + width 90°) / 3) four weeks after treatments began.

Each species was grown under blue, grey, red, or pearl CN or black shade at a 30% density. Three six-packs of each species were randomly assigned to each treatment. Each treatment was replicated three times with three controls in ambient light conditions.

The experiment was a split-plot design with treatments assigned to the main plots and plant species assigned to the sub-plots. Plants within six packs were analyzed repeated measurements. However, each species was analyzed as a separate experiment. The PROC-MIXED procedure in PC-SAS (SAS Institute, Cary, NC) was used to determine significance of the CN treatments, $P = 0.05$. Treatment differences were determined using the Bonferroni Multiple Range Test, $P = 0.05$.

Experiment two. The experiment was repeated starting November 3, 2006 with the following changes. Seeds of *Brassica oleracea* 'Blue Vantage', *Brassica oleracea* 'Patron', *Capsicum annuum* 'Sweet X3R Camelot Hybrid', *Dianthus barbatus* 'Dynasty Red', *Ipomoea tricolor* 'Crimson Rambler', *Lactuca sativa* 'Esmeralda', *Lycopersicon lycopersicum* 'Sun Leaper', and *Viola cornuta* 'Orange' were sown one seed per cell in 196-plug cell flats filled with Fafard Superfine Germination Mix (Fafard, Anderson, SC).

The seeds were covered with a thin layer of vermiculite and placed into 3.8 L (1 gal) plastic bags in a germination room with a temperature of 21.1 to 23.9C (70 to 75F) and a 24 hour overhead fluorescent light. Once the seedlings attained their first true leaves, they were placed under the same treatments as in experiment one. Twelve days after germination the plants were transplanted. Growth index and shoot height were recorded 2 and 5 weeks after treatments began.

Results and Discussion

Experiment one. There was a significant effect of treatments on shoot height of all species (Table 1). Coleus under black shade had the shortest shoots and those under ambient light had the tallest shoots. However, shoots under ambient light were similar to pearl CN. Shoots of coleus were about 11% shorter under black shade than under blue, grey, and red CN, 16% shorter under black shade than under pearl CN, and 21% shorter under black shade than under ambient light. Shoots of impatiens and sage showed a similar response to treatments with the shortest shoots under ambient light. Shoots of impatiens were about 23% shorter under ambient light than under blue, grey, red, and pearl CN and black shade. Shoots of sage were about 10% shorter under ambient light than under blue, grey, red, and pearl CN and black shade. Kale under ambient light had shorter shoots than under blue, grey, and red CN. However, shoots under ambient light were similar to pearl CN and black shade. Shoots of kale were about 18% shorter under ambient light than under blue and grey CN and 26% shorter under ambient light than under red CN. In pansy, plants grown under grey CN had shorter shoots than those under blue, red, and pearl CN and black shade. However, shoots under grey CN were similar to ambient light. Shoots of petunia were 17% shorter under black shade and ambient light than under blue CN and about 24% shorter under black shade and ambient light than under red and pearl CN.

There was a significant effect of treatments on growth index of all species (Table 2). Coleus under blue and grey CN and black shade had a smaller growth index and than under ambient light. However, all were similar to red and pearl CN. Growth index of coleus were about 20% smaller under blue and grey CN and black shade than under ambient light. In impatiens, the smallest growth index was under ambient light and the largest were under grey and pearl CN. However, grey and pearl CN were similar to red CN and black shade. Growth index of impatiens were 7% smaller under ambient light than under blue CN and 17% smaller under ambient light than under grey, red, and pearl CN and black shade. The smallest growth index in kale was under ambient light and the largest was under red CN. Growth index of kale were about 16% smaller under ambient light than under blue, grey, and pearl CN and black shade and 26% smaller under ambient light than under red CN. Pansies had a smaller growth index under grey CN and black shade than those grown under pearl CN. However, all were similar to blue and red CN and ambient light. Growth index of pansies were about 20% smaller under grey CN and black shade than under pearl CN. There was no difference among treatments for growth index in petunia. In sage, the growth index was about 12% smaller under ambient light than under blue, grey, red, and pearl CN and black shade.

The best foliage color rating in coleus was produced under ambient light (Table 3). All other treatments were equal in producing a lower color rating. Blue, grey, and red CN and black shade produced the best color ratings in impatiens, while pearl CN and ambient light produced the worst color ratings. Kale had the highest color rating under blue, grey, and red CN and the worst ratings under pearl CN and ambient light. Blue CN and black shade produced the best color rating in pansy. All other treatments were equal in producing a lower color rating in pansy. Petunia had the best color ratings under pearl CN, black shade, and ambient light. The worst ratings were found under blue, grey, and red CN. In sage, the best color ratings were produced under blue, grey, and red CN, while the worst color rating in sage was found under ambient light.

In coleus, the best compactness ratings were found under all treatments except red CN (Table 4). The most compact impatiens were under black shade and ambient light, while the least compact impatiens were under red CN. In kale, the most compact plants were under grey CN, black shade, and ambient light. Red and pearl CN produced the least compact kale plants. Grey CN and ambient light produced the most compact pansy plants, while the least compact were under blue, red, and pearl CN and black shade. In petunia, the most compact plants were produced under black shade and the least compact under pearl CN. Grey CN, black shade, and ambient light produced the best compactness rating in sage. The worst compactness ratings in sage were found under red and pearl CN.

The shortest shoots in most species were produced under ambient light conditions while the tallest shoots were under red and pearl CN. Patterns were less discernible for growth index. Ambient light produced the smallest growth index in half of the species, while red or pearl CN produced the largest growth index in half. Blue CN generally produced the best color ratings, however grey and red CN and black shade were similar to blue CN. The worst foliage color ratings were clearly found under pearl CN and ambient light. In general, grey CN, black shade, and ambient light produced the most compact plants while red and pearl CN produced the least compact plants.

The results can be partially explained based on manufacture's claims and previous research. Previous studies have shown that red CN likely resulted in stem elongation due to a resulting increase in R and FR light (5, 6). This could explain the increased shoot height and reduced plant compactness under red CN. The light scattering properties of pearl CN allow better light penetration into the plant canopy resulting in an increase in photosynthetic efficiency (11). This could have possibly accelerated plant growth resulting in taller shoots, larger growth index, and less compact plants (6). Both blue and red CN have been shown to produce plants with darker green foliage (6).

Experiment two. There was a significant effect of treatments on shoot height of all species (Table 5). Dianthus had shorter shoots under blue and grey CN and black shade than under red CN. However, shoots under blue and grey CN and black shade were similar to pearl CN and shoots under red CN were similar to ambient light. Shoots of dianthus were 30%, 25%, and 22% shorter under blue and grey CN and black shade, respectively, than under red CN. Tomatoes had the shortest shoots under grey CN and the longest under ambient light, which were similar to pearl CN. Shoots of tomatoes were about 23%, 35%, and 41% shorter under grey CN than under blue and red CN and black shade, pearl CN, and ambient light, respectively. In pepper, the shoots were 13%, 15%, 26%, 16%, and 22% shorter under black shade than under blue, pearl, grey, and red CN and ambient light. There was no difference among treatments for shoot height in viola. Morning glories had shorter shoots under black shade than under pearl, grey, and red CN. However, shoots under black shade were similar to blue CN and ambient light. Shoots of morning glories were 39%, 33%, and 29% shorter under black shade than under pearl, grey, and red CN, respectively. Broccoli had longer shoots under pearl CN than all other treatments. Shoots of broccoli were 34%, 18%, 23%, 30%, and 20 % shorter under blue, grey, and red CN, black shade, and ambient light. The shortest shoots in lettuce were under grey CN and the longest under blue CN. However, shoots under grey CN were similar to pearl CN and ambient light and shoots under blue CN were similar to red CN. Shoots of lettuce were 49% and 39% shorter under grey CN than under blue and red CN, respectively. In cabbage, the shortest shoots were under black shade and the longest under ambient light. Shoots of cabbage were 47% and 58% shorter under black shade than under blue, pearl, grey, and red CN and ambient light, respectively.

There was a significant effect of treatments on growth index of all species (Table 6). The smallest growth index in dianthus was under black shade and the largest was under pearl CN. However, growth index under black shade was similar to blue and grey CN and ambient light and growth index under pearl CN was similar to red CN. The growth index of dianthus was 26% and 19% smaller under black shade than under pearl and red CN, respectively. In tomatoes, the growth index was 14%, 23%, 14%, 9%, and 18% smaller under black shade than under blue, pearl, grey, and red CN and ambient light, respectively. Black shade and ambient light had a smaller growth index in pepper than under blue, pearl, and grey CN. However, growth index under black shade and ambient light was similar to red CN. The growth index of pepper was 25% and 20% smaller under black shade and ambient light, respectively, than under blue, pearl, and grey CN. There was no difference in growth index among viola treatments. In morning glories, grey CN had a smaller growth index than plants under all other treatments. Morning glories were 13%, 6%, 19%, 14%, and 4 % smaller under grey CN than those under blue CN, black shade, pearl and red CN, and ambient light, respectively. In broccoli, either blue or grey CN had a smaller growth index than under pearl or red CN. However, all were similar to black shade and ambient light. Growth index of broccoli was 24% and 17% smaller under blue and grey CN than under pearl and red CN, respectively. In lettuce, either pearl CN or red CN had a smaller growth index than under ambient light. However, all were similar to blue and grey CN. Growth index of lettuce was 27% smaller under pearl and red CN than under ambient light. The smallest growth index in cabbage was under black shade and the largest was under pearl CN. The growth index of cabbage was about 19%, 45%, and 26% smaller under black shade than under blue, grey, and red CN, pearl CN, and ambient light respectively

The shortest shoots were generally found under the black shade and grey CN. Pearl and red CN and ambient light produced the tallest shoots when compared to the other treatments. When looking at growth index, black shade was the most reliable at producing a small growth index and pearl CN was most reliable at producing a large growth index. These results can be partially explained based on manufacture's claims and previous research.   Previous studies have shown that red CN likely resulted in stem elongation due to a resulting increase in R and FR light (5, 6). This could explain the increased shoot height under red CN. The light scattering properties of pearl CN allow better light penetration into the plant canopy resulting in an increase in photosynthetic efficiency (11). This could have possibly accelerated plant growth resulting in taller shoots and a larger growth index (6). No one CN color was reliable for modifying growth in all species, but individual CN colors can be combined with the correct plant to produce the desired growth modification. The best treatments for producing short and compact plants would be black shade in dianthus, pepper and cabbage, black shade or grey CN in tomato and morning glory, blue CN in broccoli, and pearl CN in lettuce.

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Table 1. Effect of ChromatiNet color and ambient light on shoot height (cm) of six bedding plant species after 4 weeks of treatment, experiment 1.

	Species					
Treatment	‘Wizard Violet Red’ coleus	‘Envoy Peach Butterfly’ impatiens	‘Peacock Red’ kale	‘Delta White Blotch’ pansy	‘Celebrity Red’ petunia	‘Victoria Blue’ sage
Blue	8.3[z]b[y]	8.2a	13.3ab	8.3a	10.7ab	11.5a
Grey	8.1b	9.1a	12.6abc	6.7b	9.7bc	11.8a
Red	8.5b	8.4a	14.3a	8.1a	11.6a	11.2a
Pearl	8.8ab	8.6a	11.9bcd	7.9a	11.8a	11.7a
Black	7.4c	8.5a	11.4cd	7.3a	8.8c	11.3a
Ambient light	9.4a	6.6b	10.6d	7.1ba	9.0c	10.4b

[z]Least squares means.
[y]Mean separations in columns using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 2. Effect of ChromatiNet color and ambient light on growth index[z] of six bedding plant species after 4 weeks of treatment, experiment 1.

	Species					
Treatment	'Wizard Violet Red' coleus	'Envoy Peach Butterfly' impatiens	'Peacock Red' kale	'Delta White Blotch' pansy	'Celebrity Red' petunia	'Victoria Blue' sage
Blue	8.7[y]b[x]	9.4b	16.4b	8.4ab	11.3a	11.9a
Grey	8.3b	10.6a	16.1b	7.4b	11.4a	12.4a
Red	9.3ab	10.2ab	18.0a	8.4ab	12.1a	12.8a
Pearl	9.4ab	10.7a	15.7b	9.4a	12.0a	12.4a
Black	8.1b	10.1ab	15.4b	7.6b	11.1a	12.8a
Ambient light	10.5a	8.7c	13.3c	8.1ab	10.8a	11.0b

[z]Growth index = (height + widest width + width 90°) / 3; all measurements in cm.
[y]Least squares means.
[x]Mean separations in columns using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 3. Effect of ChromatiNet color and ambient light on foliage color rating[z] of six bedding plant species after 2 weeks of treatment, experiment 1.

	Species					
Treatment	'Wizard Violet Red' coleus	'Envoy Peach Butterfly' impatiens	'Peacock Red' kale	'Delta White Blotch' pansy	'Celebrity Red' petunia	'Victoria Blue' sage
Blue	2.0[y]a[x]	1.0b	1.0c	1.3b	1.3a	1.1c
Grey	2.0a	1.3b	1.0c	1.6a	1.2a	1.0c
Red	2.0a	1.0b	1.1c	2.1a	1.7a	1.0c
Pearl	2.0a	2.0a	3.0a	2.0a	1.0b	2.0b
Black	2.0a	1.0b	2.0b	1.0b	1.0b	2.0b
Ambient light	1.0b	1.9a	3.0a	2.0a	1.0b	3.0a

[z]Visual observation 1 to 3 scale with 1 being the best rating and 3 being the worst.
[y]Least squares means.
[x]Mean separations in columns using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 4. Effect of ChromatiNet color and ambient light on plant compactness rating[z] of six bedding plant species after 2 weeks of treatment, experiment 1.

Treatment	Species					
	'Wizard Violet Red' coleus	'Envoy Peach Butterfly' impatiens	'Peacock Red' kale	'Delta White Blotch' pansy	'Celebrity Red' petunia	'Victoria Blue' sage
Blue	1.2[y]b[x]	1.7c	2.3ab	2.7a	2.0b	2.3bc
Grey	1.2b	2.6b	2.1c	1.8b	1.9b	1.9c
Red	1.8a	3.0a	3.0a	2.6a	2.2b	3.0a
Pearl	1.0b	2.0c	3.0a	3.0a	3.0a	3.0a
Black	1.0b	1.0d	2.0c	2.7a	1.2c	2.0c
Ambient light	1.1b	1.0d	2.0c	1.8b	2.0b	2.2c

[z]Visual observation 1 to 3 scale with 1 being the best rating and 3 being the worst.
[y]Least squares means.
[x]Mean separations in columns using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 5. Effect of ChromatiNet color and ambient light on shoot height (cm) of eight bedding plant species after 5 weeks of treatment, experiment 2.

	Treatment					
Species	Blue	Black	Pearl	Grey	Red	Ambient light
‘Dynasty Red’ dianthus	5.4[z]c[y]	5.8c	6.3bc	6.0c	7.7a	7.2ab
‘Sun Leaper’ tomato	9.9bc	9.3c	11.3ab	7.3d	9.3c	12.3a
‘Sweet X3R Camelot Hybrid’ pepper	5.3a	4.6b	5.4a	6.2a	5.5a	5.9a
‘Orange’ viola	2.9a	2.5a	3.1a	2.7a	2.6a	2.5a
‘Crimson Rambler’ morning glory	10.8cd	9.1d	15.0a	13.5ab	12.9abc	11.0bcd
‘Patron’ broccoli	6.1b	6.4b	9.2a	7.5b	7.1b	7.4b
‘Esmeralda’ lettuce	7.3a	–	4.5bc	3.7c	6.1ab	5.1bc
‘Blue Vantage’ cabbage	10.8b	5.6c	10.3b	10.0b	10.9b	13.3a

[z]Least squares means.
[y]Mean separations in rows using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 6. Effect of ChromatiNet color and ambient light on growth index[z] of eight bedding plant species after 5 weeks of treatment, experiment 2.

Species	Treatment					
	Blue	Black	Pearl	Grey	Red	Ambient light
‘Dynasty Red’ dianthus	9.0[y]abc[x]	7.5c	10.1a	8.3bc	9.3ab	8.6abc
‘Sun Leaper’ tomato	12.1a	10.4b	13.5a	12.1a	11.4a	12.7a
‘Sweet X3R Camelot Hybrid’ pepper	9.7a	7.3b	9.9a	9.5a	8.7ab	7.8b
‘Orange’ viola	5.0a	4.5a	4.8a	4.6a	4.9a	4.6a
‘Crimson Rambler’ morning glory	15.1a	14.0a	16.3a	13.2b	15.3a	13.7a
‘Patron’ broccoli	9.5b	10.1ab	12.6a	9.8b	11.6a	11.1ab
‘Esmeralda’ lettuce	10.6ab	–	9.9b	10.7ab	9.9b	13.5a
‘Blue Vantage’ cabbage	12.8c	10.1d	18.3a	12.3c	12.2c	13.6b

[z]Growth index = (height + widest width + width 90°) / 3; all measurements in cm.
[y]Least squares means.
[x]Mean separations in rows using the Bonferroni Multiple Range Test, $P = 0.05$.

CHAPTER IV

THE EFFECTS OF CHROMATINET ON GROWTH OF BEDDING PLANTS

Abstract

Commercial markets require bedding plant growers to produce products that are uniform in height and are within market specifications. Chemical applications of plant growth retardants (PGRs) have been used for decades to reduce internode extension. Photoselective filters have been studied since the early nineties as an alternative to PGRs and were shown to modify plant growth. Four colors of 30% density ChromatiNet (CN), a photoselective filter produced by Polysack, were used to determine growth responses of bedding and vegetable plants *Antirrhinum majus* 'Maryland Apple Blossom', *Ageratum houstonianum* 'Blue Horizon', *Brassica oleracea* ‘Patron’, *Celosia argentea* 'Bombay Fire Apricot', *Dianthus barbatus* ‘DynastyRed’, *Ipomoea tricolor* ‘Crimson Rambler’, *Lycopersicon lycopersicum* ‘Sun Leaper’, and *Viola ×wittrockiana* 'Majestic Giant Deep Blue with Blotch'. Overall, the effects of CN color on the growth of the eight species studied were minimal. No one treatment produced the shortest or the tallest plants and the effectiveness of treatments to maintain shoot height changed from week to week making it difficult to draw any conclusions on the effectiveness of the treatments. In general, black shade resulted in the smallest growth index while ambient light resulted in

the largest. However, these results varied with species and time. Black shade produced the lowest dry weights in all species, while ambient light produced the greatest plant dry weights in all but one species, celosia. Further studies need to be conducted evaluating the effect of light intensity and the density of CN on plant response.

Index words: spectral filter, photoselective filter, growth modification, growth retardant.

Species used in this study: snapdragon (*Antirrhinum majus* L. 'Maryland Apple Blossom'), ageratum (*Ageratum houstonianum* P. Mill. 'Blue Horizon'), broccoli (*Brassica oleracea* L. 'Patron'), celosia (*Celosia argentea* L. 'Bombay Fire Apricot'), dianthus (*Dianthus barbatus* L. 'Dynasty Red'), morning glory (*Ipomoea tricolor* Cav. 'Crimson Rambler'), tomato (*Lycopersicon lycopersicum* L. 'Sun Leaper'), pansy (*Viola ×wittrockiana* Gams. 'Majestic Giant Deep Blue with Blotch').

Significance to the Nursery Industry

The ability to modify plant growth and control appearance is critical to the marketability of greenhouse produced crops. Photoselective films offer a non-chemical alternative to regulate plant growth. Commercial availability and utilization of photoselective films can potentially reduce costs for growth regulating chemicals, employee health risks, and chemical exposure to non-target ecosystems. The use of ChromatiNet (a spectral filter) is a potential means for modifying growth of greenhouse produced crops. However, results are species dependent and often temporary. In general, black shade could be used to produce smaller growth index and dry weight and ambient light could be used to produce larger growth index and dry weight.

Introduction

In the horticulture industry, growers prefer a uniform, compact plant because they are desired by consumers, easier to pack and ship, and quicker to transplant (1). Uniform, compact plants can be difficult to achieve in the close plant spacing often used in greenhouses because it can result in an uneven canopy of elongated weak stems (2). Plant growth retardants (PGRs) have been used for decades to control plant height (5), however stringent regulations now exist for their use on ornamental crops (4). The current trend is towards finding alternative avenues for producing compact plants due to the desire to meet environmental concerns over chemical use, potential government restrictions on horticultural chemicals (1), and to reduce production cost (3). Current alternatives to PGRs include: greenhouse temperature management, nutrient management, water management, and mechanical disturbance. Unfortunately, using environmental controls has not produced a consistent product (1).

An alternative method needs to be developed so that plant growth can be controlled uniformly and consistently. Manipulation of the red (R) and far-red (FR) light spectrum can alter the growth of many plant species (6). A growing environment with a high R:FR ratio favors production of short, compact plants (8).

Spectral filters, have been used experimentally to increase the R:FR ratio (9). Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) in collaboration with the

Agricultural Research Organization (The Volcani Center, Bet-Dagan, Israel) has introduced plastic shade nets for use in modifying the ambient light spectrum. A series of shade nets has been developed by the research team to modify the spectrum of filtered light, enhance the content of scattered light, and/or affect the thermal components of light in the infrared region. ChromatiNet is designed to enhance desirable physiological responses such as yield, quality, and maturation rate. The nets are made of high-density polyethylene, are stable against UV radiation for 4 to 5 years (7), and offer varying mixes of natural, unmodified light and spectrally modified, diffused light depending on the pigmentation of the plastic and the density of the knitting design (10).

Blue ChromatiNet was shown to reduce the transmittance of the R, FR, and UV spectrums and increase blue spectrum transmission (11). Blue ChromatiNet inhibits elongation, reduces side branching, shortens internode length, and has the ability to postpone flowering so that flowering time can be adjusted to meet market requirements (6, 7).

According to Polysack, grey ChromatiNet refracts light through its special crystalloid material which allows for better light distribution (7). It creates a thermo-reflective barrier, absorbing infrared radiation and therefore creating a cooler microclimate (11, 12). Plants grown under grey ChromatiNet show an increase in the number of shoots and buds and a noticeable increase in branching (6, 12).

Red ChromatiNet reduces the spectrum of blue, green, and yellow light and increases the R and FR light spectrum. This creates plants with a larger surface area, healthier, darker green foliage, and longer, thicker stems. Polysack claims that red

ChromatiNet produces higher quality, earlier flowering plants without decreasing flower quality (7).

Pearl ChromatiNet has the ability to scatter incoming light allowing the light to better penetrate the plant canopy, resulting in increased photosynthetic efficiency (11). This accelerated plant growth, increased the number of secondary branches, and overall improved plant quality (7).

The objective of this study was to evaluate the effects of several ChromatiNet colors on the growth of bedding and vegetable plant species grown in a greenhouse environment.

Materials and Methods

The experiment was started on December 22, 2006 at the Auburn University Greenhouse Facility (Auburn, AL). Seeds of eight bedding and vegetable plants, *Antirrhinum majus* 'Maryland Apple Blossom', *Ageratum houstonianum* 'Blue Horizon', *Brassica oleracea* 'Patron', *Celosia argentea* 'Bombay Fire Apricot', *Dianthus barbatus* 'Dynasty Red', *Ipomoea tricolor* 'Crimson Rambler', *Lycopersicon lycopersicum* 'Sun Leaper', and *Viola ×wittrockiana* 'Majestic Giant Deep Blue with Blotch' were sown directly into 11.4 cm (4.5 in) pots containing Fafard 3B Mix (Fafard, Anderson, SC). Pots were placed on metal benches in an unshaded greenhouse with a heat set point of 18.3C (65F) and ventilation beginning at 25.5C (78F). The greenhouse was covered with 8 mm (0.32 in) twin-wall polycarbonate.

Fifteen netting support structures, 162×112×45 cm (63.8×44.1×17.6 in) in size, were constructed of 1.9 cm (0.75 in) SCH 40 PVC. ChromatiNet (CN) in blue, grey, red, or pearl or black shade (Polysack Plastic Industries, Ltd., Nir-Yitzhak, Sufa, Israel) was placed in a single layer on top of each structure and attached with 20.3 cm (8 in) cable ties at the base of each structure allowing the netting to drape over the top and around the sides to the bench surface. Once the seedlings attained their first true leaves, eight plants of each species were placed under each treatment replication. Ageratum was placed under treatments on December 24 and other species were placed under treatments on December 27.

The plants were fertilized from planting with a 10.5N-1.76P-12.32K (14-4-14 CAL-P-MAG, Total Gro. TM, Winnsboro, LA), applied at a rate of 150 ppm N through a Dosatron (Tresses, France) injector. Fertilizer was applied three out of every four waterings.

Shoot height and widths were recorded to calculate growth index (height + widest width + width 90°) / 3) two, four, and six weeks after treatments began. Morning glory was harvested at four weeks when plants became large enough to grow into the netting and interfere with the growth of other species. At six weeks, the remaining plants were harvested at the soil line and placed into labeled paper bags for shoot dry weight determination. They were put into a forced air drying oven (Precision Scientific Company, Chicago, IL) at approximately 79C (174.2F) for 72 hours.

Each species was grown under blue, grey, red, or pearl CN or black shade at a 30% density. Eight plants of each species were randomly assigned to each treatment. Each treatment was replicated three times with three controls in ambient light conditions.

The experiment was a split-plot design with CN treatments assigned to the main plots and plant species assigned to the sub-plots. The main plot replications were blocked for an anticipated light intensity gradient in the greenhouse. However, each species was subsequently analyzed as separate experiments. The PROC-MIXED procedure in PC-SAS (SAS Institute, Cary, NC) was used to determine significance of the CN treatments, P= 0.05. Treatment differences were determined using the Bonferroni Multiple Range Test, P= 0.05.

Results and Discussion

There was a significant interaction of treatments on shoot height of most species (Table 1). Shoot heights of ageratum, broccoli, and pansy were not affected by treatments. Celosia under ambient light had shorter shoots than under other treatments for all three time periods. However, shoots under ambient light were similar to blue CN at two weeks, pearl CN at four weeks, and black shade at six weeks. Shoots of celosia were about 26% shorter under ambient light than under black shade and red and pearl CN at two weeks, 23%, 23%, and 11% shorter under ambient light than under black shade and blue and red CN, respectively, at four weeks, and 19% shorter under ambient light than under blue, red, and pearl CN at six weeks. Shoot heights of dianthus at two weeks were not significant. At four weeks, dianthus had shorter shoots under pearl CN than under black shade, but all were similar to blue and red CN and ambient light. Dianthus was 12% shorter under pearl CN than under black shade. At six weeks, the shortest shoots were under black shade and the longest were under ambient light. However, ambient light was similar to blue, red, and pearl CN. Shoots of dianthus were 18%, 21%, 28%, and 35% shorter under black shade than under blue, red, and pearl CN and ambient light, respectively. At two weeks, morning glories had shorter shoots under blue and red CN and ambient light than under black shade, but all were similar to pearl CN. Morning glories were 22%, 32%, and 26% shorter under blue and red CN and ambient light, respectively, than under black shade. At four weeks, morning glories had shorter shoots under ambient light than under black shade and red CN, but all were similar to blue and pearl CN. Morning glories were about 21% shorter under ambient light than under black shade and red CN. Shoot heights of snapdragons at two weeks were not significant. In snapdragon, the shortest shoots were under blue CN and the longest under black shade, pearl CN, and ambient light, at four weeks. However, shoots under blue CN were similar to red CN. Snapdragon shoots were about 12% and 28% shorter under blue CN than under black shade and pearl CN and ambient light, respectively. At six weeks, the shortest snapdragon shoots were under black shade and blue CN and the longest shoots were under ambient light. Shoots were 18%, 16%, and 32% shorter under black shade and blue CN than under red and pearl CN and ambient light, respectively. At two weeks, tomatoes shoots were shorter under black shade and blue CN than under red and pearl CN and ambient light. Shoots were about 20% shorter under black shade and blue CN than under red and pearl CN and ambient light. Tomatoes shoots were shortest under pearl CN and longest under red CN, at four weeks. However, shoots under pearl CN were similar to black shade and blue CN and shoots under red CN were similar to blue CN, and ambient light. Shoots of tomatoes were 17% shorter under ambient light than under rd CNN. At six weeks, tomatoes had shorter shoots under pearl CN than under red

CN and ambient light, but all were similar to black shade and blue CN. Shoots were 11% and 16% shorter under pearl CN than under red CN and ambient light, respectively.

There was a significant interaction of treatments on growth index of most species (Table 2). Growth index of broccoli and morning glories were not affected by treatments. At two weeks after treatments began, ageratum had a 22% smaller growth index under black shade than under pearl CN and ambient light. However, growth index of all were similar to blue and red CN. At four weeks, ageratum had a smaller growth index under black shade and blue CN than under pearl CN and ambient light, but all were similar to red CN. Ageratum was about 18% and 13% smaller under black shade and blue CN, respectively, than under pearl CN and ambient light. The growth index of ageratum was 15% smaller under black shade than under ambient light at six weeks. However, growth index of both were similar to blue, red, and pearl CN. Celosia was about 14% smaller under ambient light than under black shade and red CN and pearl CN at two weeks, but all were similar to blue CN. At four weeks, celosia had a smaller growth index under red and pearl CN and ambient light than under black shade and blue CN. Celosia was about 15% smaller under red and pearl CN and ambient light than under black shade and blue CN. At six weeks, the smallest growth index was under black shade and the largest under blue CN. However, black shade was similar to pearl CN and ambient light and blue CN was similar to red and pearl CN. The growth index of celosia was 17% smaller under black shade than under blue CN. At two weeks, the growth index of dianthus under black shade and red CN were smaller than under ambient light, but all were similar to blue and pearl CN. The growth index was 20% and 12% smaller under black shade and red CN, respectively, than under ambient light. The growth index at four weeks was smaller under red CN than under black shade, but both were similar to blue and pearl CN and ambient light. Dianthus was 24% smaller under red CN than under black shade. At six weeks, the smallest growth index of dianthus was under black shade and the largest under ambient light. However, the growth index under ambient light was similar to pearl CN. Growth index were 26%, 13%, and 16% smaller under black shade and blue and red CN, respectively, than under ambient light. At two weeks, the smallest growth index in snapdragons was under black shade and the largest growth was under ambient light. However, black shade was similar to blue and pearl CN and ambient light was similar to red CN. The growth index was 27% smaller under black shade than under ambient light. At four and six weeks, snapdragons under black shade and blue CN had the smallest growth index and snapdragons under ambient light had the largest growth index. However, snapdragons under ambient light were similar to under pearl CN, at four weeks. Snapdragons were 23%, 21%, and 11% smaller under black shade and blue CN and red CN, at four weeks. Snapdragons were about 12%, 12%, and 24% smaller under black shade and blue CN than under red and pearl CN and ambient light, respectively, at six weeks. At two weeks, tomatoes under black shade and blue and pearl CN were smaller than tomatoes grown under red CN and ambient light. Tomatoes were about 18%, 13%, and 13% smaller under black shade and blue and pearl CN, respectively, than under red CN and ambient light. At four weeks, tomatoes were smaller under black shade and pearl CN than under blue and red CN and ambient light. Tomatoes were about 14% smaller under black shade and pearl CN under blue and red CN and ambient light. At six weeks, tomatoes were 31% smaller under pearl CN than under ambient light. However, both pearl CN and ambient light were similar to black shade and blue and red CN. In pansies, the smallest growth index at two and four weeks were under pearl CN and the largest was under blue CN. Pansies were about 16% smaller under pearl CN than under blue CN and about 8% smaller under pearl CN than under ambient light. However, pearl CN was similar to black shade and blue CN was similar to red CN, at two weeks. Pearl CN was similar to both black shade and red CN, at four weeks. At six weeks, pansies were smaller under black shade and pearl CN than under ambient light. However, growth index of all were similar to blue and red CN. Pansies were 13% smaller under black shade and pearl CN than under ambient light.

There was a significant interaction of treatments on dry weights of most species (Table 3). Dry weights of broccoli, morning glory, and tomato were not affected by treatments. The lowest dry weight in ageratum was under black shade and the greatest was under ambient light. Dry weight of ageratum was about 7% and 14% lower under black shade than under blue, red, and pearl CN and ambient light, respectively. Dry weights in celosia under black shade, red and pearl CN, and ambient were about 4% lower than celosia under blue CN. The lowest dry weights in dianthus were under black shade and red CN and the greatest was under ambient light. Dry weights of dianthus were 5%, 5%, and 10% lower under black shade and red CN than under blue and pearl CN and ambient light, respectively. In snapdragons, the lowest dry weights were under black shade and red CN and the greatest was under ambient light. However, dry weight of snapdragons under black shade was similar to dry weight under blue CN. Dry weight of snapdragons was 4%, 5%, and 12% lower under black shade than under red and pearl CN and ambient light, respectively. The lowest dry weight in pansies was under black shade and the greatest was under ambient light. However, dry weight of pansies under black shade was similar to pansies under red and pearl CN and dry weight of pansies under ambient light was similar to pansies under blue CN. Pansy dry weight was about 5% lower under black shade than under ambient light.

Overall, the effects of CN color on the growth of the eight species studied were minimal. No one treatment produced the shortest or the longest shoot height and the effectiveness of treatments to maintain shoot height changed from week to week making it difficult to draw any conclusions on the effectiveness of the treatments. In general, black shade resulted in the smallest growth index while ambient light resulted in the largest. However, these results were highly variable and not consistent in all species. Black shade produced the lowest dry weights in all species, while ambient light produced the greatest dry weights in all but one species, celosia.

The results of this study do not correlate to the current literature and manufacture's claims on CN. Blue CN should have inhibited elongation and shortened internode length (7) resulting in shorter shoot height. Shortest shoot height only occurred under blue CN in three species and was not consistently the shortest for all weeks of data collection. Red CN should have produced plants with the longest stems (7), but this only consistently occurred in tomatoes. The scattering properties of pearl CN should have allowed light to better penetrate the plant canopy, resulting in increased efficiency of photosynthesis (11) and accelerated plant growth (7). There was no indication that pearl CN produces these results based on dry weights.

We are unsure why the CN showed little results in this study. This study was conducted during an unusually overcast winter. Perhaps the effects of CN are reduced when overall light intensity is reduced. Further studies need to be conducted evaluating the effect of light intensity and the density of CN on plant response.

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Table 1. Effect of ChromatiNet color and ambient light on shoot height (cm) of selected bedding plants 2, 4, and 6 weeks after treatments began.

	'Bombay Fire Apricot' celosia				
Week	Black	Blue	Red	Pearl	Ambient light
2	4.9[z]a[y]	4.1bc	4.6ab	5.1a	3.6c
4	8.3a	8.3a	7.2b	7.0bc	6.4c
6	11.4bc	12.9ab	13.4a	12.6ab	10.4c
	'Dynasty Red' dianthus				
2	3.9a	4.0a	3.9a	3.9a	3.8a
4	8.2a	7.4ab	7.8ab	7.2b	7.4ab
6	8.9c	10.9b	11.3ab	12.3ab	12.8a
	'Crimson Rambler' morning glory				
2	16.8a	13.1b	11.4b	14.0ab	12.4b
4	69.2a	58.8ab	64.0a	58.5ab	52.3b
	'Maryland Apple Blossom' snapdragon				
2	2.1a	2.0a	2.8a	2.1a	2.4a
4	6.0b	5.3c	5.8bc	6.1b	7.4a
6	13.2c	14.2c	16.7b	16.2b	18.9a
	'Sun Leaper' tomato				
2	8.0b	7.6b	9.6a	9.8a	9.8a
4	16.5bc	17.4abc	18.9a	15.6c	18.0ab
6	24.1ab	24.2ab	24.7a	21.9b	26.0a

[z]Least squares means.
[y]Mean separations in rows using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 2. Effect of ChromatiNet color and ambient light on growth index[z] of selected bedding plants 2, 4, and 6 weeks after treatments began.

Week	Black	Blue	Red	Pearl	Ambient light
	'Blue Horizon' ageratum				
2	3.9b	4.4ab	4.4ab	5.0a	5.0a
4	8.5b	9.0b	9.4ab	10.2a	10.5a
6	14.6b	16.1ab	16.7ab	16.4ab	17.2a
	'Bombay Fire Apricot' celosia				
2	3.9a	3.8ab	4.0a	4.0a	3.4b
4	7.6a	7.5a	6.6b	6.3b	6.3b
6	9.3c	11.2a	10.8ab	10.3abc	9.9bc
	'Dynasty Red' dianthus				
2	4.1b	4.9ab	4.5b	4.8ab	5.1a
4	10.8a	9.1ab	8.2b	9.4ab	10.4ab
6	11.8c	13.5b	14.0b	14.7ab	15.9a
	'Maryland Apple Blossom' snapdragon				
2	2.4c	2.7bc	3.0ab	2.6bc	3.3a
4	5.8c	5.9c	6.6b	7.0ab	7.5a
6	10.7c	11.4c	12.5b	12.6b	14.4a
	'Sun Leaper' tomato				
2	10.8b	11.5b	13.3a	11.5b	12.9a
4	21.5b	24.3a	25.1a	21.3b	24.9a
6	31.6ab	31.2ab	30.3ab	26.0b	37.9a
	'Majestic Giant Deep Blue with Blotch' pansy				
2	3.4bc	3.9a	3.8ab	3.3c	3.5b
4	5.8bc	6.8a	6.1bc	5.7c	6.3b
6	8.7b	9.2ab	9.4ab	8.7b	10.0a

[z]Growth index = (height + widest width + width 90°) / 3; all measurements in cm.
[y]Least squares means.
[x]Mean separations in rows using the Bonferroni Multiple Range Test, $P = 0.05$.

Table 3. Effect of ChromatiNet color and ambient light on shoot dry weight (g) of selected bedding plants 6 weeks after treatments began.

Cultivar	Black	Blue	Red	Pearl	Ambient light
‘Blue Horizon’ ageratum	7.6[z]c[y]	8.1b	8.2b	8.2b	8.8a
‘Bombay Fire Apricot’ celosia	7.1b	7.4a	7.1b	7.0b	7.1b
‘Dynasty Red’ dianthus	7.1c	7.5b	7.1c	7.5b	7.9a
‘Maryland Apple Blossom’ snapdragon	7.3c	7.5bc	7.6b	7.7b	8.3a
‘Majestic Giant Deep Blue with Blotch’ pansy	7.3c	7.6ab	7.4bc	7.4bc	7.7a

[z]Least squares means.
[y]Mean separations in rows using the Bonferroni Multiple Range Test, $P = 0.05$.

CHAPTER V

FINAL DISCUSSION

The purpose of these studies was to evaluate the application of ChromatiNet (CN) as a growth modifying photoselective filter. The purpose of the first study was to evaluate the application of CN in a high tunnel for improving cut flower stem length and diameter of snapdragon (*Antirrhinum majus*). Three cultivars of snapdragons, 'Potomac Pink', 'Potomac Royal', and 'Potomac Yellow', were grown under blue, grey, red, or pearl CN or black shade at 30% density or ambient light in a high tunnel. Inflorescence length and fresh weights was not affected by treatments. In general, red and pearl CN produced the longest stems in 'Potomac Pink' and 'Potomac Royal'. However, black shade produced the longest stems in 'Potomac Yellow'. There was no correlation between stem length and stem diameter and no consistent stem diameter response among the three cultivars in response to the CN treatments. Perhaps subtle genetic differences among the cultivars or flooding and drought conditions attributed to these results. In cut flower production of snapdragons, longer stem length receives a higher price in the marketplace, so using red or pearl CN in production should generally yield a higher quality cut flower that commands a higher price.

While the first study was on stem elongation, subsequent studies were concentrated on producing more compact bedding plants. Commercial markets require growers of bedding plants to produce a product that has uniform height and is within preset specifications. In chapter three, four CN colors (blue, grey, red, or pearl), black shade, or ambient light were used in two experiments to determine growth responses of eight bedding and vegetable plants. In the first experiment, *Brassica oleracea* 'Kale Peacock Red', *Impatiens walleriana* 'Envoy peach Butterfly', *Petunia floribunda* 'Celebrity Red', *Salvia farinacea* 'Victoria Blue', *Solenostemon scutellarioides* 'Wizard Violet Red', and *Viola ×wittrockiana* 'Delta White Blotch' were used. The shortest shoots in most species were under ambient light conditions while the tallest shoots were under red and pearl CN. Patterns of treatment effects were less discernible for growth index. Ambient light produced the smallest growth index in half of the species and pearl CN produced the largest growth index in half. Blue CN generally produced the best color ratings, however grey and red CN and black shade were similar to blue CN. The worst foliage color ratings were clearly found under pearl CN and ambient light. In general, grey CN, black shade, and ambient light produced the most compact plants and red and pearl CN produced the least compact plants.

In the second chapter three experiment, *Brassica oleracea* 'Blue Vantage', *Brassica oleracea* 'Patron', *Capsicum annuum* 'Sweet X3R Camelot Hybrid', *Dianthus barbatus* 'Dynasty Red', *Ipomoea tricolor* 'Crimson Rambler', *Lactuca sativa* 'Esmeralda', *Lycopersicon lycopersicum* 'Sun Leaper', and *Viola cornuta* 'Orange' were used. The shortest shoots were generally found under black shade and grey CN. Pearl and red CN and ambient light produced the tallest shoots when compared to the other treatments. For growth index, black shade was the most reliable at producing a smaller growth index and pearl CN was most reliable at producing a larger growth index. No one CN color reliably modified growth in all species, but individual CN colors could be combined with the correct plant to produce the desired growth modification. The best treatments for producing short and compact plants would be black shade in dianthus, pepper and cabbage, black shade or grey CN in tomato and morning glory, blue CN in broccoli, and pearl CN in lettuce.

In the chapter four, *Antirrhinum majus* 'Maryland Apple Blossom', *Ageratum houstonianum* 'Blue Horizon', *Brassica oleracea* 'Patron', *Celosia argentea* 'Bombay Fire Apricot', *Dianthus barbatus* 'DynastyRed', *Ipomoea tricolor* 'Crimson Rambler', *Lycopersicon lycopersicum* 'Sun Leaper', and *Viola ×wittrockiana* 'Majestic Giant Deep Blue with Blotch' were used. Overall, the effects of CN color on the growth of the eight species studied were minimal. No one treatment produced the shortest or the longest shoot height and the effectiveness of treatments to maintain shoot height changed from week to week making it difficult to draw any conclusions on the effectiveness of the treatments. In general, black shade resulted in the smallest growth index while ambient light resulted in the largest. However, these results were highly variable and not consistent in all species. Black shade produced the lowest dry weights in all species, while ambient light produced the largest dry weights in all but one species, celosia.

The stem elongation effect of red and pearl CN in chapters two and three was to be expected based on manufacture’s claims and previous research. Previous studies have shown that red CN produced taller plants than black shade controls (1, 3). Red CN likely resulted in a stem elongation effect due to the increase in red and far-red light (1, 2). This could explain the increased shoot height and reduced plant compactness under red CN. Red CN should have resulted in thicker snapdragon stems in chapter two (3), however this was only the case in 'Potomac Yellow'. The light scattering properties of pearl CN allow better light penetration into the plant canopy resulting in an increase in photosynthetic efficiency (4). This could explain accelerated plant growth resulting in taller shoots, larger growth index, and less compact plants in chapters two and three (3). Stem lengths in 'Potomac Yellow' could not be explained by the current literature.

The results in chapter four do not correlate to the current literature or manufacture’s claims on CN. Blue CN should have inhibited stem elongation and shortened internode length resulting in shorter shoot height. Shortest shoot height only occurred under blue CN in three species and was not consistently the shortest for all weeks of data collection. Red CN should have produced plants with the longest stems, but this only consistently occurred in tomatoes (3). The scattering properties of pearl CN should have allowed light to better penetrate the plant canopy, resulting in increased photosynthetic efficiency (4) and accelerated plant growth (3). There was no indication that pearl CN produces these results based on dry weights.

Overall, the effects of CN on plant growth were species dependent. In most cases, red and pearl CN produced the tallest, largest plants. Black shade and ambient light generally produced the shortest, smallest plants, but ambient light resulted in the tallest shoots in chapter three, experiment two and the largest growth index in chapter four. Studies were conducted at various times of year and results seem to vary with season. Perhaps the effects of CN are reduced when overall light intensity is reduced. Further studies need to be conducted evaluating the effect of light intensity and the density of CN on plant response.

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