The Effects of Colored Mulch and ChromatiNet® on Select Cut Flower and Vegetable Production in a High Tunnel Production System

by

William Garlin Sherrer

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Approved by

J. Raymond Kessler Jr., Chair, Professor of Horticulture
Wheeler G. Foshee III, Associate Professor of Horticulture
James E. Brown, Professor of Horticulture

Abstract

The objective of these studies was to determine the effects of colored plastic mulch on the quality of select cut flowers in a high tunnel production system. In the first study, snapdragons (*Antirhinum majus*) were evaluated on red, white, or blue plastic mulch. Blue mulch produced the longest stems for all cultivars except 'Supreme Gold Yellow'. White mulch produced the longest stems for 'Potomac Orange'. 'Potomac Orange' and 'Supreme Gold Yellow' produced the longest stems among the cultivars on blue mulch. White and Blue mulch produced the thickest stems. 'Potomac Yellow' produced the thickest stems. White and blue plastic mulch produced the longest inflorescences. 'Potomac Orange', 'Potomac Yellow', and 'Supreme Gold Yellow' produced the longest inflorescences. Blue and white plastic mulch produced the best cut flower characteristics in snapdragon when grown July to October. 'Potomac Orange' followed by 'Supreme Gold Yellow' followed by 'Potomac Yellow' yielded the best results for late summer snapdragon production. In the second study snapdragons and dianthus (*Dianthus barbatus* interspecific) were evaluated on red, white, blue, black, or bare ground in a high tunnel production system. 'Cool Bronze' produced the longest stems on black, red, and white mulch. 'Cool White' produced the longest stems on black, blue, and red mulch. 'Cool Bronze' produced the thickest stem diameters. Black and blue plastic mulch produced the thickest stems. 'Cool White', 'Cool Bronze', and 'Cool Rose' had the same inflorescence lengths. There was no difference between black, blue, red, and white mulches for inflorescence lengths. In dianthus, black and blue mulch produced the most stems per plant and the longest stems. There were no differences in open flowers per stem rating among the mulch treatments.

Black and blue plastic mulch produced the best cut flower characteristics in snapdragon and dianthus October to February. 'Cool Bronze' followed by 'Cool White' yielded the best results for late fall production of snapdragons.

The purpose of this research was to evaluate the application of ChromatiNet® shade cloth in a high tunnel production system for improving fruit yield of colored bell pepper (*Capsicum annuum*). In two studies, the bell pepper varieties 'Tequila' and 'Stiletto' in the first, and 'Magno' and 'Permit' in the second were grown under blue, gray, pearl, or red ChromatiNet® shade cloth, black shade cloth, or no shade cloth. In the first study, 'Stiletto' had the highest marketable fruit numbers with blue, pearl, and red shade and no shade. For 'Tequila', there were no differences in marketable fruit numbers among the shade cloth treatments. 'Tequila' had more unmarketable fruit than 'Stiletto', and both varieties had the highest unmarketable fruit numbers with black, blue, gray, and red shade and no shade. The highest marketable and unmarketable fruit weights for 'Stiletto' were with black and red shade, respectively, and for 'Tequila' were no shade and pearl shade, respectively. 'Stiletto' had higher marketable and unmarketable fruit weights than 'Tequila' with all shade treatments except unmarketable fruit weight with black shade. Marketable fruit numbers and weights were highest for both varieties in the second harvest, but decreased sharply thereafter. In the second study, the first two harvests, 'Magno' had higher marketable fruit numbers and weights than 'Permit'. For the first harvest, both varieties produced the highest numbers of marketable fruit under red, gray, and no shade. For the second harvest, it was red shade. For the third harvest it was black shade. For the fourth and fifth harvests it was black and red shade. For the sixth harvest it was the same for all shade cloth colors. For the first harvest, both varieties had higher marketable fruit weights with red and grey shade. For the second harvest, it was red shade. Unmarketable fruit numbers were generally highest for ‘Permit’ in the fifth harvest, second to last harvest, and the last harvest. Unmarketable fruit numbers were generally highest for ‘Magno’ in the second to last harvest. ‘Magno’ had higher unmarketable fruit numbers than ‘Permit’ in the first three, the sixth, and the next to last harvests. ‘Magno’ had higher unmarketable fruit numbers with no shade across all harvests, while ‘Permit’ showed no differences. Unmarketable fruit weights were highest in the next to last harvest for ‘Magno’ and the last for ‘Permit’. ‘Magno’ had higher unmarketable fruit weights than ‘Permit’. Across all harvests, ‘Magno’ had the highest unmarketable fruit weights with no shade, and ‘Permit’ had the highest unmarketable fruit weights with red shade. Many factors likely contributed to the variability in response of the bell pepper varieties used in these studies to the shade treatments. ‘Tequila’ and ‘Magno’ generally yielded more than ‘Stiletto’ and ‘Permit’. Because of the variability among varieties, dates of harvest, and colored shade cloth treatments, we are unable to ascertain a definitive shade cloth treatment that would improve colored bell pepper yield in a high tunnel production system under all conditions. Further research needs to be done on the subject to reach a clearer conclusion.

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Chapter I

Literature Review

Cut Flowers

Most of the cut flowers sold in the U.S. are imported from Columbia and the Netherlands (18). The Miami International Airport (Miami, FL USA) received more than 11 million boxes carrying a total of 340,000 tons of cut flowers per year for U.S. consumption. This accounts for two-thirds of the $13 billion in annual cut flower retail sales in the U.S. A cash value of $675 million in cut flowers was imported into Miami from 1994 to 1995. Most of these imports were coming from South America, primarily Columbia. John F. Kennedy International Airport in New York City imports about 21,780 tons of cut flowers per year. The Netherlands was the primary exporter to this airport, but Israel, South Africa, Thailand, Australia, and New Zealand also contributed.

Despite this volume of cut flower imports, the U.S. market has demand for domestically grown cut flowers. Locally grown cut flowers can be delivered fresh to the florist eliminating problems associated with shipping and the extra cost. For example, snapdragons (*Antirrhinum majus*) must be stored and shipped upright because the stems will bend upwards if they are not (1). This, and their need for refrigeration can cause problems with importation into the U.S. Warm temperature exposure of snapdragons on airport loading docks can decrease their usability in floral arrangements.

Demand by florists for spike flowers, a wide range of colors, and high stem strength of modern snapdragon cultivars reserves their spot in the U.S. cut flower markets (1). According to preliminary data from the USDA, over 46 million snapdragon stems were sold at wholesale in 2006 at a total value of over $12 million (19). There are four response groups that snapdragon cultivars are placed in based on optimum response to growing conditions (3). Cultivars grown in winter and early spring are in Group I, cultivars grown in late winter and spring are in Group II, cultivars grown in late spring and fall are in Group III, and cultivars grown in summer are in Group IV. Due to cold temperature requirements, Group I cultivars should not be grown in the southeast. Group II cultivars flower from December 15 to April 1 in the south, while Group III cultivars flower from April 1 to June 1 and from November 1 to December 15. Group IV cultivars flower from June 1 to November 1 (3; 14). Grading snapdragon cut flowers is based on stem length, stem weight, and number of open florets.

Dianthus barbatus interspecific is available in a wide range of colors and cultivars that are well suited for the U.S. cut flower market (1). Preliminary data shows that a wholesale value of over $31 million miniature/spray carnations was imported into the U.S. in 2006 (19). No additional information about *Dianthus barbatus* interspecific use as a cut flower was found.

Colored Bell Peppers

Capsicum annuum includes both pungent (hot) and nonpungent (mild) peppers; colored bell peppers are nonpungent (8). Twenty-four percent of all Americans consume at least one food containing bell peppers on any given day. Likewise, 10% of U.S. consumers used fresh-market bell peppers, and 16% used processed peppers (frozen, canned, and dried). Gross receipts from bell peppers rose 32% over the previous 5 years, and annual farm receipts for sweet bell peppers averaged $535 million with an estimated retail value of over $1.7 billion for all uses from 1998 to 2000. Domestic shipments of peppers peak in year-round production and marketing during May and June, while import shipments peak during the winter months.

Fresh-market bell peppers are imported to the U.S. from Mexico, the Netherlands, and Canada (8). Mexico imports the largest amount of field-grown bell peppers in the winter. Bell peppers imported from the Netherlands and Canada to the U.S. are grown in greenhouses. They are grown in 48 U.S. states with California leading production, followed closely by Florida, and by New Jersey, Georgia, and North Carolina as the top five producing states in 2000. Most bell peppers are sold commercially in the fresh market.

Fresh-market, field-grown peppers are typically harvested by hand each week over the course of about a month (8). Most bell peppers are sold as mature green peppers, but growers receive a premium price for a limited amount of other fruit colors. This premium price reflects the fact that bright colored peppers are more costly to produce because field losses are higher, and yields are lower than those of bell peppers harvested at the mature green stage. Red bell peppers are the mature stage of most green bell peppers that have been allowed to ripen on the plant. Fruit sugar content increases as the pepper matures making most of the brighter colored peppers sweeter tasting than green peppers. Most bell pepper cultivars can be used in both processing and fresh-market sales making the bell pepper a dual-market product.

Plasticulture

"Plasticulture, simply defined, is a system of growing crops wherein a significant benefit is derived from using products made from plastic polymers" (5). Polyethylene polymers were first invented and subsequently developed in the late 1930's. Polyethylene was one of the first plastics produced on a commercial scale in 1939 that was easy to process, resistant to chemicals, durable, flexible, and relatively odorless and nontoxic (22). Polyethylene plastic films, mulches, and drip irrigation tubing and tape were introduced in the late 1950's for use in commercial vegetable production giving rise to plasticulture (5). Polyethylene mulch is used to cover raised beds that are generally 10.2 cm to 15.2 cm (4 to 6 in) tall, 76.2 cm (30 in) wide, and have a slope of 3.2 cm (1.25 in) from the center of the bed to its edge.

Most of the research on the effects of colored polyethylene mulches on crop production has been focused on vegetable production. However, there has been little research on colored plastic mulches' possible benefits in ornamental and cut flower production. More current research on cut flower production showed some of the benefits of using these mulches.

Experiments at Auburn, AL and Cullman, AL evaluated the effects of colored plastic mulches on cut flower size and yield of *Antirhinum majus* 'Sonnet Mix', *Penstemon digitalis* 'Husker's Red', *Achillea* 'Coronation Gold', and *Dianthus barbatus* 'Bouquet Purple' (2). Treatments were black, red, white, or blue plastic films; pine bark; or bare ground. There was variability in the results between locations for yarrow, snapdragon, and dianthus because of climate differences between the two locations. There were only a few small effects on penstemon. Snapdragons grown in Auburn on red film had 28% longer stems than those grown on pine bark, but in Cullman, white plastic produced 12% longer stems than those on pine bark. Fifty more stems per plot were produced on black plastic than on bare ground and white plastic in Auburn. The longest stems of dianthus produced at Auburn were grown on black plastic, which were 14% longer than bare ground. Dianthus also produced eight more stems per plot on white plastic compared to that on bare ground. White plastic mulch produced the longest dianthus stems in Cullman, AL which were 21% longer than those grown on pine bark. Red plastic film produced the highest dianthus stem count, producing 13 more stems per plot than pine bark which had the lowest stem count. The longest yarrow stems at Auburn were produced on blue and black plastic which were 8% longer than those produced in pine bark. Blue and white plastic produced the largest yarrow flower diameters in Cullman, AL with flower heads that were 17% larger than pine bark. In Auburn, AL, red plastic produced flower heads that were 22% larger in diameter than those grown in pine bark.

The Penn State Center for Plasticulture has performed extensive studies over the last 10 years on the affects of mulch color on yield of vegetable crops (12). Tomatoes, peppers, eggplants, cantaloupe, cucumbers, and summer squash averaged a 12%, 20%, 12%, 35%, 30%, and 20% increases in marketable yield when grown on red, silver, red, green infrared thermal or dark blue, dark blue, or dark blue plastic mulch, respectively, when compared to black mulch over a 2-3 year period. Onions and potatoes grown on several different mulch colors including red, metalized silver, and black averaged a 24% increase in marketable bulb or tuber yield over eight varieties, respectively, when compared to those grown with no plastic mulch.

Penn State has found some inconsistencies in results from colored plastic mulch studies. Red, blue, yellow, gray or black mulches were used with bare ground as the control to grow ‘Sunbeam’ tomatoes, ‘Gold Rush’ zucchini, and ‘Majestic’ cauliflower in the 1993 study (10). In this follow up study, temperatures were 5^{o}C warmer under all the plastic colors than in a 1992 study. In previous studies tomatoes had responded best to red mulch, but in 1993 the highest yields were found on blue and gray mulches. They surmised that this may have been due to the light reflectance from the mulch. In the 1992 study, zucchini responded to blue mulch, but in the 1993 study, its highest yields were harvested on red, yellow, or black mulches. They propose that the high soil temperatures under the blue mulch may have caused this result. Summer production of cauliflower on colored mulches yielded no yield differences. However, cauliflower heads were larger for plants grown on colored mulches when compared to bare ground control.

High Tunnels

High tunnels are simplified growing systems that enhance crop growth, yield, and quality (21). High tunnels are nonpermanent, infield structures, lacking electrical service, automated ventilation, and permanent heating systems, though temporary heaters may be used during frosts, that resemble traditional polyethylene covered greenhouses, but is a completely different technology (22, 21). High tunnels consist of a pipe or other materials framework covered in a single layer of greenhouse-grade 4 mm (0.16 in) to 6 mm (0.24 in) polyethylene plastic while most traditional greenhouses use a double layer of plastic (6, 20). High tunnels are ventilated by manually rolling the side walls up and down with a roll bar that runs the length of the tunnel and depends on cross winds to provide ventilation, while a traditional greenhouse uses an automated ventilation system and fans to circulate air (22, 21).

High tunnels are much more economical than automated greenhouses that have higher capital cost and higher maintenance expenses (21). A high tunnel could be constructed in 1998 relatively inexpensively, at about $1.25 per 0.3048 m^2 (square foot). High tunnels are used for growing season extension in the spring and fall. Using season extension, crops can be planted earlier and fruit picked sooner allowing them to be sent to market sooner than crops in an outdoor cropping system. Disease control is another benefit of high tunnels. The plastic layer serves as a barrier against moisture and disease spores.

High tunnels benefit cut flower production by offering more production options ranging from herbaceous perennials being over-wintered for spring cut flower production to summer annuals, and natural fall-season chrysanthemums (7). The high tunnel production system provides excellent flower quality and makes it possible to harvest cut flowers earlier in the spring and later in the fall than in an open air, field-grown, production system.

Penn State performed a study to determine if high tunnels could lower the cost of heating for pansy production (4). In mid-October, they transplanted Dynamite Complete Mix and Mulberry Shades pansies from 128 cell plugs to 10.2 cm (4 in) pots which were then placed into one of the six treatments: traditional greenhouse at 60° F (15.5° C) (the control), unheated high tunnel with the pots on benches covered with overwintering cover, unheated high tunnel with pots on benches without cover, unheated high tunnel with the pots on the floor covered with overwintering cover, unheated high tunnel with pots on floor without cover, or outdoors with overwintering cover. The overwintering covers were not put over the pansies until early December. There was little difference whether the plants were covered or uncovered and whether they were on benches or the floor. The plants that were outside did not grow during the winter. The pansies could be finished in a heated greenhouse in six weeks with an estimated overhead cost of $0.19 per pot. In the high tunnel, they would be finished in 20 weeks with an overhead cost of $0.13 per pot. The good crop quality, minimal labor, and reasonable overhead cost made the researchers conclude that high tunnels look promising for the overwintering of pansies and similar crops.

Photomorphogenesis

The term photomorphogenesis is used to designate the control that can be exerted by radiant energy over growth and development of a plant, independent of photosynthesis (9). Plant response to different colored mulches is due to the combination of two factors: an increase in soil temperature from the plastic mulch, and the range of wavelengths of radiant energy reflected by individual mulch colors (11). Plants are sensitive to the radiant energy wavelengths leaves intercept from the sun and reflected surfaces such as plastic mulches. Different color mulches absorb and reflect different radiant energy wavelengths, thus affecting plants differently. The largest plant growth responses are produced by red and far-red light (600-800 nm). A lower far-red to red ratio causes plants to develop larger roots and shorter stems. A higher far-red to red ratio causes plants to direct more new growth into shoots, resulting in a taller plant with more leaves. Different colored plastic mulches reflect different wavelengths yielding different far-red to red ratios.

ChromatiNet®

Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) manufactures colored shade cloths called ChromatiNet® advertised as improving utilization of solar radiation by agricultural crops (13). Polysack claims this technology promotes differential stimulation of desirable physiological responses in plants thus, increasing the commercial value of crops. ChromatiNet® is advertised as an economical and environmentally friendly alternative to labor-intensive procedures, such as pruning and thinning, and the widespread use of growth regulators and other chemicals that most growers currently use. Growers should be able to control vegetative growth characteristics, such as leaf size, branch length, and plant height by using the proper ChromatiNet® color in production (13). Polysack further claims control of the rate of flowering and maturation with this product. This added control allows growers to manipulate maturation so their products can meet market demands.

ChromatiNet® Red Shade Net changes the solar radiant energy transmitted to plants by reducing the blue, green, and yellow spectrums and increasing the red and far-red spectrums (13). According to Polysack, plant development under red radiant energy increases leaf surface area, stems are longer and thicker, and total foliage volume is higher. Polysack claims ChromatiNet® Red Shade Net causes earlier flowering without decreasing flower quality. ChromatiNet® Grey Shade Net blocks infra-red radiant energy and distributes the remaining by refraction through the special crystalloid structure of the grey net filament. ChromatiNet® Pearl Shade Net diffuses direct solar radiation when it passes through the threads, causing the radiation to cover many more plant parts, especially the lower stems and leaves. This increases photosynthetic efficiency, accelerates growth, and improves product quality. The number of secondary branches is also increased by the diffused light in many plants, greatly benefiting stem and leaf production.

There has been very little published research on ChromatiNet® outside of Israel. In one study, Shahak (16) compared commercially grown bell peppers under 30-40% black shade cloth to ones grown under red, yellow or pearl shade cloths in the Besor area of Israel. Colored shade nets produced 30-40% more fruit per plant than black. Marketable fruit was 20-30% higher under the colored nets than under black. Fruit size was similar across treatments. Fruit grown under colored nets was smaller than those grown under black shade cloth in August and September, but this trend reversed late in the harvest season. Red shade net produced better results than yellow or pearl.

Shahak, et al. (15) also performed a study using fruit trees in a commercial orchard in Bar'am kibbutz, north of Israel. The orchard was planted in 1996 with alternating double rows of 'Topred', 'Red Delicious', and 'Golden Smoothee Delicious', and occasional single rows of 'Black John' grown on a Hashabi rootstock. Eight rows of trees were covered horizontally about 4.5 m above the ground with red, blue, grey or pearl at a 30% shade rate, white or red/white shade cloth at 15% shade rate about 4.5 m above the ground, and an un-shaded control. The first season fruit set was not reduced by the netting as the experimenters expected it to be. 'Golden Smoothee Delicious' had increased fruit number under all the shade treatments, especially under the red/white net when compared to the un-shaded control. Fruit size was larger under shade treatments with fruit up to 5 mm larger in diameter than the control by mid summer. The nets cooled the canopies enough to prevent fruit damage in a four-day heat wave. About a month before harvest, ‘Top Red’ had visibly better red coloration under the nets than the control. ‘Top Red’ had the best coloration under the grey netting.

Shahak, et al. (15) also did a colored net study on ‘Hermosa’ peaches grafted onto ‘Balady’ rootstocks. He used a 7 year old commercial orchard in Re’em, central Israel. Blue, red, yellow, grey, or pearl 30% colored shade cloth and a 12% white shade cloth were applied horizontally 4.5 m above the ground over the top of the trees. The shade was applied only 6 weeks before harvest in 2001, but resulted in better fruit size and color for most treatments in that little time. Grey produced the earliest fruit and the best red color. In two harvests, 75% of the peaches were harvested under the grey shade when compared to only 38% from the control. Fruit under red and yellow shades were exceptionally firmer and sweeter than was expected for their large size. Ten months later, shade improved flowering and fruit-set. High quality juvenile fruit were especially pronounced under red. Grey, red, yellow, and pearl nets produced the largest fruit. Fruit size was smaller under blue and the control. Trees under shade developed healthier, more intensive new flushes. Sooty mold didn’t occur under shade like it did on the control.

Stephens (17) grew the ornamental chili pepper, ‘Explosive Ember’, in New South Wales under no shade, or red, blue, or gray shade nets. After 8 weeks, the control had the best leaf color, but attracted the most insect pests. Blue produced the shortest plants. Red produced more branches and attracted fewer thrips or other insect pests than the other treatments. Even though red gave the best results, differences were not large enough for red shade cloth to be installed on a large scale at the researcher's facility. Gray produced the tallest plants, bushier plants than the control, and the poorest foliage color. Gray did not reduce pests significantly.

Stephens (17) also used 'Eclipse' ivy geranium (*Pelargonium peltatum*) with the same colored shade cloth treatments. The control produced the shortest plants and the shortest internodes. Blue produced the longest leaves in the study. Grey produced the longest internodes and wider leaves than the control, but the fewest branches, flowers, and buds. Red produced the tallest plants and the shortest leaves, but leaves were wider than the control. Red produced the most branches, flowers, and buds.

There is a need for more research into the uses of colored mulches and ChromatiNet® on a wider variety of crops in the southeastern United States. The research on ChromatiNet® especially needs to be broadened from its base in Israel. As research continues into the use of colored plastic mulches and ChromatiNet® in the green industry, growers and farmers will reap the benefits of these new technologies.

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Chapter II

The Effects of Colored Mulch on Cut Flower Production in a High Tunnel Production System

Abstract

The objective of these studies was to determine the effects of colored plastic mulch on the quality of select cut flowers in a high tunnel production system. In the first study, snapdragons (*Antirhinum majus*) were evaluated on red, white, or blue plastic mulch. Blue mulch produced the longest stems for all cultivars except 'Supreme Gold Yellow'. White mulch produced the longest stems for 'Potomac Orange'. 'Potomac Orange' and 'Supreme Gold Yellow' produced the longest stems among the cultivars on blue mulch. White and blue mulch produced the thickest stems. 'Potomac Yellow' produced the thickest stems. White and blue plastic mulch produced the longest inflorescences. 'Potomac Orange', 'Potomac Yellow', and 'Supreme Gold Yellow' produced the longest inflorescences. Blue and white plastic mulch produced the best cut flower characteristics in snapdragon when grown July to October. 'Potomac Orange' followed by 'Supreme Gold Yellow' followed by 'Potomac Yellow' yielded the best results for late summer snapdragon production. In the second study snapdragons and dianthus (*Dianthus barbatus* interspecific) were evaluated on red, white, blue, black, or bare ground in a high tunnel production system. 'Cool Bronze' produced the longest stems on black, red, and white mulch. 'Cool White' produced the longest stems on black, blue, and red mulch. 'Cool Bronze' produced the thickest stem diameters. Black and blue plastic mulch produced the thickest stems. 'Cool White', 'Cool Bronze', and 'Cool Rose' had the same inflorescence

lengths. There was no difference between black, blue, red, and white mulches for inflorescence lengths. In dianthus, black and blue mulch produced the most stems per plant and the longest stems. There were no differences in open flowers per stem rating among the mulch treatments. Black and blue plastic mulch produced the best cut flower characteristics in snapdragon and dianthus October to February. ‘Cool Bronze’ followed by ‘Cool White’ yielded the best results for late fall production of snapdragons.

Index Words: snapdragons (*Antirrhinum majus*), Dianthus (*Dianthus barbatus* interspecific), colored plastic mulch

Species List: snapdragons (*Antirrhinum majus* L.) ‘Potomac Apple Blossom’, ‘Supreme Gold Yellow’, ‘Potomac Yellow’, ‘Potomac Orange’, ‘Potomac Pink’, ‘Cool Bronze’, ‘Cool Rose’, and ‘Cool White’, Dianthus (*Dianthus barbatus* interspecific ‘Amazon Neon Purple’)

Significance to the Nursery Industry

In the first study ‘Potomac Apple Blossom’, ‘Supreme Gold Yellow’, ‘Potomac Yellow’, ‘Potomac Orange’, and ‘Potomac Pink’ snapdragons were transplanted on July 30, 2007 into raised beds covered with either red, white, or blue plastic mulch in a high tunnel in Shorter, AL. Fencing was installed horizontally over the seedlings to provide plant support. The cut flowers were harvested when two-thirds of a plot of plants had open flowers. Harvests occurred September 24 and 29, and October 2 and 8, 2007. The flower stems were cut as close to the ground as possible with pruners. Measurements were recorded of each stem’s length, diameter [30.48 cm (12 in) from the base], and inflorescence length (from the lower most floret on a stem to the tip of the inflorescence). Blue and white plastic mulch produced the best cut flower characteristics in snapdragon when grown July to October. ‘Potomac Orange’ followed by ‘Supreme Gold Yellow’ followed by ‘Potomac Yellow’ yielded the best results for late summer snapdragon production. In the second study Cool Bronze', 'Cool Rose', and 'Cool White' snapdragons and 'Amazon Neon Purple' dianthus were transplanted on October 19, 2007 into raised beds covered with blue, black, red, or white polyethylene mulch or bare ground in a high tunnel in Headland, AL. The cut flowers were harvested when two-thirds of a plot of plants had open flowers. Snapdragons were harvested from January 3, 2008 to February 29, 2008, and dianthus were harvested from February 16, 2008 to February 29, 2008. The flower stems were cut as close to the ground as possible with pruners. Measurements were recorded for the snapdragons of each stem's length, diameter [30.48 cm (12 in) from the base], and inflorescence length (from the lower most floret on a stem to the tip of the inflorescence). The number of stems per plant and the length of each stem were recorded for the dianthus. An open flowers per stem rating was assigned to each stem with the scale of 0=0 to 9 flowers, 1=10 to 19 flowers, 2=20 to 29 flowers, 3=30 to39 flowers, 4=40 to 49 flowers, 5=50 to 59 flowers, 6=60 to 69 flowers, and 7=70 to79 flowers. Black and blue plastic mulch produced the best cut flower characteristics in snapdragon and dianthus October to February. 'Cool Bronze' followed by 'Cool White' yielded the best results for late fall production of snapdragons.

Introduction

Demand by florists for spike flowers, a wide range of colors, and high stem strength of modern snapdragon cultivars reserves their spot in the U.S. cut flower markets (1). According to preliminary data from the USDA, over 46 million snapdragon stems were sold at wholesale in 2006 at a total value of over $12 million (11). There are four response groups that snapdragon cultivars are placed in based on optimum response to growing conditions (3). Cultivars grown in winter and early spring are in Group I, cultivars grown in late winter and spring are in Group II, cultivars grown in late spring and fall are in Group III, and cultivars grown in summer are in

Group IV. Due to cold temperature requirements, Group I cultivars should not be grown in the southeast. Group II cultivars flower from December 15 to April 1 in the south, while Group III cultivars flower from April 1 to June 1 and from November 1 to December 15. Group IV cultivars flower from June 1 to November 1 (3; 10). Grading snapdragon cut flowers is based on stem length, stem weight, and number of open florets.

Dianthus barbatus interspecific is available in a wide range of colors and cultivars that are well suited for the U.S. cut flower market (1). Preliminary data shows that a wholesale value of over $31 million miniature/spray carnations were imported into the U.S. in 2006 (11). No additional information about *Dianthus barbatus* interspecific use as a cut flower was found.

High tunnels are simplified growing systems that enhance crop growth, yield, and quality (13). High tunnels are nonpermanent, infield structures, lacking electrical service, automated ventilation, and permanent heating systems, though temporary heaters may be used during frosts, that resemble traditional polyethylene covered greenhouses, but is a completely different technology (14, 13). High tunnels consist of a pipe or other materials framework covered in a single layer of greenhouse-grade 4 mm (0.16 in) to 6 mm (0.24 in) polyethylene plastic while most traditional greenhouses use a double layer of plastic (4, 12). High tunnels are ventilated by manually rolling the side walls up and down with a roll bar that runs the length of the tunnel and depends on cross winds to provide ventilation, while a traditional greenhouse uses an automated ventilation system and fans to circulate air (14, 13).

High tunnels are much more economical than automated greenhouses that have higher capital cost and higher maintenance expenses (13). A high tunnel could be constructed in 1998 relatively inexpensively, at about $1.25 per 0.3048 m^2 (square foot). High tunnels are used for growing season extension in the spring and fall. Using season extension, crops can be planted earlier and fruit picked sooner allowing them to be sent to market sooner than crops in an outdoor cropping system. Disease control is another benefit of high tunnels. The plastic layer serves as a barrier against moisture and disease spores.

High tunnels benefit cut flower production by offering more production options ranging from herbaceous perennials being over-wintered for spring cut flower production to summer annuals, and natural fall-season chrysanthemums (5). The high tunnel production system provides excellent flower quality and makes it possible to harvest cut flowers earlier in the spring and later in the fall than in an open air, field-grown, production system.

Experiments at Auburn, AL and Cullman, AL evaluated the effects of colored plastic mulches on cut flower size and yield of *Antirhinum majus* 'Sonnet Mix', *Penstemon digitalis* 'Husker's Red', *Achillea* 'Coronation Gold', and *Dianthus barbatus* 'Bouquet Purple' (2). Treatments were black, red, white, or blue plastic films; pine bark; or bare ground. There was variability in the results between locations for yarrow, snapdragon, and dianthus because of climate differences between the two locations. There were only a few small effects on penstemon. Snapdragons grown in Auburn on red film had 28% longer stems than those grown on pine bark, but in Cullman, white plastic produced 12% longer stems than those on pine bark. Fifty more stems per plot were produced on black plastic than on bare ground and white plastic in Auburn. The longest stems of dianthus produced at Auburn were grown on black plastic, which were 14% longer than bare ground. Dianthus also produced eight more stems per plot on white plastic compared to that on bare ground. White plastic mulch produced the longest dianthus stems in Cullman, AL which were 21% longer than those grown on pine bark. Red plastic film produced the highest dianthus stem count, producing 13 more stems per plot than pine bark which had the lowest stem count. The longest yarrow stems at Auburn were produced on blue and black plastic which were 8% longer than those produced in pine bark. Blue and white plastic produced the largest yarrow flower diameters in Cullman, AL with flower heads that were 17% larger than pine bark. In Auburn, AL, red plastic produced flower heads that were 22% larger in diameter than those grown in pine bark.

The Penn State Center for Plasticulture has performed extensive studies over the last 10 years on the affects of mulch color on yield of vegetable crops (9). Tomatoes, peppers, eggplants, cantaloupe, cucumbers, and summer squash averaged a 12%, 20%, 12%, 35%, 30%, and 20% increases in marketable yield when grown on red, silver, red, green infrared thermal or dark blue, dark blue, or dark blue plastic mulch, respectively, when compared to black mulch over a 2-3 year period. Onions and potatoes grown on several different mulch colors including red, metalized silver, and black averaged a 24% increase in marketable bulb or tuber yield over eight varieties, respectively, when compared to those grown with no plastic mulch.

The term photomorphogenesis is used to designate the control that can be exerted by radiant energy over growth and development of a plant, independent of photosynthesis (6). Plant response to different colored mulches is due to the combination of two factors: an increase in soil temperature from the plastic mulch, and the range of wavelengths of radiant energy reflected by individual mulch colors (8). Plants are sensitive to the radiant energy wavelengths leaves intercept from the sun and reflected surfaces such as plastic mulches. Different color mulches absorb and reflect different radiant energy wavelengths, thus affecting plants differently. The largest plant growth responses are produced by red and far-red light (600-800 nm). A lower far-red to red ratio causes plants to develop larger roots and shorter stems. A higher far-red to red ratio causes plants to direct more new growth into shoots, resulting in a taller plant with more leaves. Different colored plastic mulches reflect different wavelengths yielding different far-red to red ratios.

Because vegetables responded beneficially to different colored plastic mulches, it may be that cut flowers species could benefit from the same treatments. In cut flowers, the longer the stem length and the higher the quality rating, then the greater the wholesale price will be (10). Stem diameter, inflorescence length, and stem count are also important attributes of cut flowers that could be beneficially affected by the use of colored plastic mulches. These experiments were conducted to determine the effects of different plastic mulch colors on cut flower production in a high tunnel production system. Snapdragons and dianthus were selected as the cut flowers to be evaluated because of their importance to the US cut flower market and their potential for local production in local fresh markets. Therefore, the objective of these studies was to determine which color of plastic mulch produces the best cut flower snapdragons for summer to fall production and snapdragons and dianthus for fall to winter production in a high tunnel.

Materials and Methods

The first experiment was conducted in the summer and fall of 2007 at the Auburn University, E.V. Smith Research Center (Shorter, AL U.S.A. latitude: 32.394N. longitude: -85.916W.) on a Marvyn sandy loam (fine-loamy, kaolinitic, thermic typic Kanhapludults) soil type. A gothic arch, high tunnel (Ledgewood Farm, Moultonborough, NH) was covered with a single layer of 0.15 mm (0.006 in) polyethylene. The high tunnel was positioned on a north/south longitudinal axis, and its dimensions were 6.4 m W × 14.6 m L × 2.7 m H (21 ft W × 48 ft L × 9 ft H). Wiggle-wire locks were attached 1.2 m (4 ft) above the base to allow for rollup sides that were rolled up for passive cooling.

There were no soil amendments added before planting. Raised beds 46 cm (18 in) wide and 20.3 cm (8 in) tall were laid and covered with polyethylene mulch using a mulch bedder (Reddick Fumigants, Wilmington, NC). Three plastic mulch colors were used: red, white, and blue (Pliant Corporation, Schaumburg, IL). Each bed had one line of T-Tape® (T-Systems International, San Diego, CA) in the center and under the mulch that delivered 1.7 Lpm/30.5 m (0.45 gpm/100 ft).

Snapdragon seedlings were obtained in 288 plug flats from a seedling grower (Ball Seed, West Chicago, IL). The snapdragon cultivars were 'Potomac Apple Blossom', 'Supreme Gold Yellow', 'Potomac Yellow', 'Potomac Orange', and 'Potomac Pink' snapdragons (Group III). Plants were transplanted into the raised beds on July 30, 2007 at a spacing of 12.7 cm (5 in) between rows and 10.2 cm (4 in) in the rows.

Plots consisted of eighteen seedlings per plot and were set up as three rows of six seedlings per row. Two replications of each cultivar were planted within each experimental unit (row) of colored mulch; there were three replications of each mulch color. The experimental design used was a split-plot with the colored mulch main plots completely randomized; and the snapdragon cultivars were completely randomized within the colored mulch replications.

Once the seedlings resumed growth, 0.61 m (2 ft) wide MaxiGrid Warning Barrier (Easy Gardener Products Waco, TX) fencing was installed horizontally over the seedlings to provide plant support. Fi-Shock (Woodstream Corporation Lititz, PA) 1.23 m (4 ft) Step-In Fence Posts were set on either side of the beds to support the fencing. The fencing was moved higher as the plants grew taller to provide support for the stems. The cut flowers were harvested when two-thirds of a plot of plants had open flowers. Harvests occurred September 24 and 29, and October 2 and 8, 2007. The flower stems were cut as close to the ground as possible with pruners. The stems were tied into one bundle for each plot and put into clean garbage cans with water. The cut flowers were stored in a walk-in cooler (Kolpak, Brooklyn, NY) at 3.3 º C (38 º F). They were stored in the cooler for a maximum of 48 hours. Measurements were recorded of each stem's length, diameter [30.48 cm (12 in) from the base], and inflorescence length (from the lower-most floret on a stem to the tip of the inflorescence).

SAS version 9.1.3 (SAS, Institute, Inc., Cary, SC) was used to analyze the data. PROC MIXED was used to test main effects and interactions at $\alpha = 0.05$, and differences in means were determined using Bonferroni's Multiple Comparison method at $\alpha = 0.05$. Open flower ratings were analyzed using PROC GLIMMIX and the multinomial probability distribution with at $\alpha = 0.05$. Individual flower stems were analyzed as sub-samples.

A second experiment used the same methods as the first except as follows: it was conducted in the fall of 2007 and the winter of 2008. 'Cool Bronze', 'Cool Rose', and 'Cool White' (Group I to early/mid II) snapdragon seedlings in 392 plug flats and 'Amazon Neon Purple' dianthus seedlings in 200 plug flats (Ball Seed Company, West Chicago, Illinois) were delivered on October 9, 2007 and were placed in a greenhouse at the Paterson Greenhouse Facility at Auburn University, Alabama. Seedlings were fertilized at 150 ppm N using a 20-4.4-16.6 (20-10-20) (Peters Professional® The Scotts Company LLC, Marysville, Ohio) water soluble fertilizer every other time they required water. The seedlings were planted in a 8.5 m W × 29.3 m L × 3.7 m H (28 ft W × 96 ft L × 12 ft H) (Atlas, Alapaha, GA) high tunnel at the Wiregrass Experiment Station in Headland, Alabama U.S.A. (latitude 31.351N. longitude -85.342W.) on October 19, 2007. The soil type was a Dothan sandy loam soil (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Blue, black, red, or white polyethylene mulch or bare ground was each randomly assigned to three 2.1 m (7 ft) long plots. The mulch plots were divided into three equal sections, the three cultivars were randomly assigned to the sections, and eighteen seedlings of each cultivar were planted per section. The seedlings were spaced 10.16 cm by 10.16 cm (4 in by 4 in). The dianthus plots were set up the same way as the snapdragons, however, dianthus was spaced 25.4 cm by 25.4 cm (10 in by 10 in) with 12 plants per plot.

Snapdragons were harvested from January 3, 2008 to February 29, 2008, and dianthus were harvested from February 16, 2008 to February 29, 2008. All except for one harvest of dianthus were processed within 24 hours of their harvest without any refrigeration. The number of stems per plant and the length of each stem were recorded for dianthus. An open flowers per stem rating was assigned for dianthus to each stem with the scale of: 0=0 to 9 flowers, 1=10 to 19 flowers, 2=20 to 29 flowers, 3=30 to39 flowers, 4=40 to 49 flowers, 5=50 to 59 flowers, 6=60 to 69 flowers, and 7=70 to79 flowers.

Results

In the first study, there was an interaction between cultivar and mulch color for stem length. Blue mulch produced the longest stems for all cultivars except 'Supreme Gold Yellow' (Table 1). White mulch produced the longest stems for 'Potomac Orange'. 'Potomac Orange' and 'Supreme Gold Yellow' produced the longest stems among the cultivars on blue mulch. There were only main effects for cultivar and mulch stem diameters. White and blue mulch produced the thickest stems. 'Potomac Yellow' produced the thickest stems. There were only main effects for cultivar and mulch color for inflorescence lengths. White and blue plastic mulch produced the longest inflorescences. 'Potomac Orange', 'Potomac Yellow', and 'Supreme Gold Yellow' produced the longest inflorescences.

In the second study, with snapdragons, there was an interaction between cultivar and mulch color for stem length. 'Cool Bronze' produced the longest stems on black, red, and white mulch (Table 2). ‘Cool White’ produced the longest stems on black, blue, and red mulch. There were only main effects for stem diameter. ‘Cool Bronze’ produced the thickest stem diameters. Black and blue plastic mulch produced the thickest stems. There were only main effects for cultivar and mulch color for inflorescence lengths. ‘Cool White’, ‘Cool Bronze’, and ‘Cool Rose’ had the same inflorescence lengths. There was no difference between black, blue, red, and white mulches for inflorescence lengths. In dianthus, black and blue mulch produced the most stems per plant and the longest stems (Table 3). There were no differences in open flowers per stem rating among the mulch treatments.

The longer the stem length and higher quality rating, yield the greater wholesale price in snapdragon cut flowers (10). Blue and white plastic mulch produced the best cut flower characteristics in snapdragon when grown July to October. ‘Potomac Orange’ followed by ‘Supreme Gold Yellow’ followed by ‘Potomac Yellow’ yielded the best results for late summer snapdragon production. Black and blue plastic mulch produced the best cut flower characteristics in snapdragon and dianthus October to February. ‘Cool Bronze’ followed by ‘Cool White’ yielded the best results for late fall production of snapdragons.

In experiments at Auburn, AL and Cullman, AL (2) the study was conducted outdoors from October to July of the next year. In this first study, the experiment was conducted from July to October, and in this second study, the experiment was conducted from October to February. The differences in the length and season of the studies may account for some of the differences in results. In experiments at Auburn, AL and Cullman, AL, snapdragons produced longer stems on red plastic in Auburn and on white plastic in Cullman. In this research, blue and white mulch produced the longest stems in Shorter, AL. In this research at Headland, AL, ‘Cool Bronze’ produced the longest stems on black, red, and white mulch and ‘Cool White’ produced the longest stems on black, blue, and red mulch. In experiments at Auburn, AL and Cullman, AL, dianthus produced longer stems on black plastic in Auburn and on white plastic in Cullman, AL. In this research, black and blue plastic produced the longest stems in Headland, AL. In experiments at Auburn, AL and Cullman, AL, dianthus produced the highest stem counts on red plastic at both locations. In this research, black and blue plastic produced the highest stem counts in Headland. Location and time of year may have affected the temperatures under the plastic and account for differences in snapdragon's response to mulch color between Shorter and Headland. Orzolek et al., (7) reported that in addition, changes in sun angle with respect to the earth's surface during the fall and winter season may also change the red : far-red wavelength ratio reflected from the different plastic mulch colors.

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Table 1. Effects of plastic mulch color on cut flower size in snapdragon cultivars in 2007.

Mulch color	Blue	White	Red
Cultivar		Stem length (cm)[z]	
Potomac Apple Blossom	86.3bA[y]	81.1cB	78.0bB
Potomac Orange	96.8aA	96.3aA	88.7aB
Potomac Pink	87.0bA	86.7bcB	79.3bC
Potomac Yellow	83.6bA	80.7cB	80.8bB
Supreme Gold Yellow	94.2aNS	89.2bNS	92.6aNS
Cultivar	Stem diameter (mm)[x]	Mulch color	Stem diameter (mm)
Potomac Apple Blossom	4.0c	Blue	5.2a
Potomac Orange	5.3b	White	5.3a
Potomac Pink	5.4b	Red	4.8b
Potomac Yellow	5.7a		
Supreme Gold Yellow	5.1c		
Cultivar	Inflorescence length (cm)[x]	Mulch color	Inflorescence length (cm)
Potomac Apple Blossom	14.3b	Blue	15.9ab
Potomac Orange	16.6a	White	16.5a
Potomac Pink	14.5b	Red	14.5b
Potomac Yellow	15.2ab		
Supreme Gold Yellow	17.5a		

[z]The cultivar × mulch color interaction was significant, $\alpha = 0.05$.
[y]Least squares means. Mean separation within columns (lower case) and rows (upper case) using Bonferroni's test, $\alpha = 0.05$, NS = not significant.
[x]Only the main effects were significant, $\alpha = 0.05$.

Table 2. Effects of plastic mulch color on cut flowers size in snapdragon cultivars in 2007-2008.

Cultivar	Cool Bronze	Cool Rose	Cool White
Mulch	Stem length (cm)[z]		
Bare ground	81.1cA[y]	72.5nsB	84.3bA
Black	102.7aA	79.6nsB	100.5aA
Blue	95.3bA	78.3nsB	88.2aA
Red	95.6aA	73.2nsC	87.6aB
White	97.6aA	75.6nsC	86.6bB
Cultivar	Stem diameter (mm)[x]	Mulch color	Stem diameter (mm)
Cool Bronze	5.3a	Bare ground	3.9d
Cool Rose	4.2c	Black	5.4a
Cool White	4.8b	Blue	5.1ab
		Red	4.7bc
		White	4.6cd
Cultivar	Inflorescence length (cm)[x]	Mulch color	Inflorescence length (cm)
Cool Bronze	21.1a	Bare ground	17.0b
Cool Rose	16.8ab	Black	19.7a
Cool White	21.8a	Blue	21.9a
		Red	22.1a
		White	18.9a

[z]The cultivar × mulch color interaction was significant, α = 0.05.
[y]Least squares means. Mean separation within columns (lower case) and rows (upper case) using Bonferroni's test, α = 0.05, NS = not significant.
[x]The cultivar × mulch color was not significant, α = 0.05.

Table 3. Effects of plastic mulch color on cut flowers size in dianthus 'Amazon Neon Purple' in 2007-2008.

Mulch	Stem count per plant	Stem length (cm)
Bare ground	5c[z]	57.4c
Black	10a	63.2a
Blue	9ab	61.0ab
Red	7bc	59.9bc
White	7bc	59.8bc

[z]Least squares means. Mean separation within columns using Bonferroni's test, $\alpha = 0.05$.

Chapter III

The Effects of ChromatiNet® on Colored Bell Pepper Production in a High Tunnel Production System

Abstract

The purpose of this research was to evaluate the application of ChromatiNet® shade cloth in a high tunnel production system for improving fruit yield of colored bell pepper (*Capsicum annuum*). In two studies, the bell pepper varieties 'Tequila' and 'Stiletto' in the first, and 'Magno' and 'Permit' in the second were grown under blue, gray, pearl, or red ChromatiNet® shade cloth, black shade cloth, or no shade cloth. In the first study, 'Stiletto' had the highest marketable fruit numbers with blue, pearl, and red shade and no shade. For 'Tequila', there were no differences in marketable fruit numbers among the shade cloth treatments. 'Tequila' had more unmarketable fruit than 'Stiletto', and both varieties had the highest unmarketable fruit numbers with black, blue, gray, and red shade and no shade. The highest marketable and unmarketable fruit weights for 'Stiletto' were with black and red shade, respectively, and for 'Tequila' were no shade and pearl shade, respectively. 'Stiletto' had higher marketable and unmarketable fruit weights than 'Tequila' with all shade treatments except unmarketable fruit weight with black shade. Marketable fruit numbers and weights were highest for both varieties in the second harvest, but decreased sharply thereafter. In the second study, the first two harvests, 'Magno' had higher marketable fruit numbers and weights than 'Permit'. For the first harvest, both varieties produced the highest numbers of marketable fruit under red, gray, and no shade. For the second harvest, it was red shade. For the third harvest it was black shade. For the

fourth and fifth harvests it was black and red shade. For the sixth harvest it was the same for all shade cloth colors. For the first harvest, both varieties had higher marketable fruit weights with red and grey shade. For the second harvest, it was red shade. Unmarketable fruit numbers were generally highest for ‘Permit’ in the fifth harvest, second to last harvest, and the last harvest. Unmarketable fruit numbers were generally highest for ‘Magno’ in the second to last harvest. ‘Magno’ had higher unmarketable fruit numbers than ‘Permit’ in the first three, the sixth, and the next to last harvests. ‘Magno’ had higher unmarketable fruit numbers with no shade across all harvests, while ‘Permit’ showed no differences. Unmarketable fruit weights were highest in the next to last harvest for ‘Magno’ and the last for ‘Permit’. ‘Magno’ had higher unmarketable fruit weights than ‘Permit’. Across all harvests, ‘Magno’ had the highest unmarketable fruit weights with no shade, and ‘Permit’ had the highest unmarketable fruit weights with red shade. Many factors likely contributed to the variability in response of the bell pepper varieties used in these studies to the shade treatments. ‘Tequila’ and ‘Magno’ generally yielded more than ‘Stiletto’ and ‘Permit’. Because of the variability among varieties, dates of harvest, and colored shade cloth treatments, we are unable to ascertain a definitive shade cloth treatment that would improve colored bell pepper yield in a high tunnel production system under all conditions. Further research needs to be done on the subject to reach a clearer conclusion.

Species List: bell peppers (*Capsicum annuum* L. ‘Stiletto’, ‘Tequila’, ‘Permit’, and ‘Magno’)

Chemical List: Hero™ Insecticide (Mustang Max) Bifenthrin Zeta-cypermethrin; Rampage® (Assault) Bromethalin

Significance to the Nursery Industry

High tunnels are nonpermanent, infield structures that resemble a greenhouse, but are covered with only a single layer of polyethylene, used to extend the growing season and provide some disease control by acting as a physical barrier to moisture and fungal spores. Colored bell peppers are bell peppers that have been allowed to reach full maturity. They fetch a higher price than mature green peppers do at market. Colored shade cloths (ChromatiNet®) are advertised as being able to improve plant attributes by way of manipulating the solar radiation utilized by the plants, but most of the research of these claims has been performed in Israel where ChromatiNet® was developed. These two studies were performed to evaluate the effects of colored shade cloths on colored bell pepper yield in raised beds covered with white polyethylene mulch in a high tunnel in Alabama. 'Stiletto' (red) and 'Tequila' (purple) were used in the first study, and 'Magno' (orange) and 'Permit' (red) were used in the second study. Red, blue, gray, or pearl ChromatiNet®, black shade cloth at 30% light reduction, or no shade cloth were applied over Fi-Shock 1.23 m (4 ft) Step-In Fence Posts set on either side of two rows of peppers. There were six plants per 3.0 m (10 ft) plot of each variety spaced 45.72 cm (18 in) apart within the row, and three replications of each colored shade cloth treatment. Bell peppers were harvested whenever they reached full mature color. Fruit was graded and counted as marketable or unmarketable. Marketable fruit was close to U.S. Fancy grade, 3 or 4 lobed, well developed with no blemishes, and able to stand up on their own. Unmarketable fruit was marketable fruit, but not as high a grade as marketable. All fruit in each grade was weighed from each plot.

Many factors likely contributed to the variability in response of the bell pepper varieties used in these studies to the shade treatments. 'Tequila' and 'Magno' generally yielded more than 'Stiletto' and 'Permit'. Because of the variability among varieties, dates of harvest, and colored shade cloth treatments, we are unable to ascertain a definitive shade cloth treatment that would improve colored bell pepper yield in a high tunnel production system under all conditions. Further research needs to be done on the subject to reach a clearer conclusion.

Introduction

Capsicum annuum includes both pungent (hot) and nonpungent (mild) peppers; colored bell peppers are nonpungent (2). Twenty-four percent of all Americans consume at least one food containing bell peppers on any given day. Likewise, 10% of U.S. consumers used fresh-market bell peppers, and 16% used processed peppers (frozen, canned, and dried). Gross receipts from bell peppers rose 32% over the previous 5 years, and annual farm receipts for sweet bell peppers averaged $535 million with an estimated retail value of over $1.7 billion for all uses from 1998 to 2000. Domestic shipments of peppers peak in year-round production and marketing during May and June, while import shipments peak during the winter months.

Fresh-market bell peppers are imported to the U.S. from Mexico, the Netherlands, and Canada (2). Mexico imports the largest amount of field-grown bell peppers in the winter. Bell peppers imported from the Netherlands and Canada to the U.S. are grown in greenhouses. They are grown in 48 U.S. states with California leading production, followed closely by Florida, and by New Jersey, Georgia, and North Carolina as the top five producing states in 2000. Most bell peppers are sold commercially in the fresh market.

Fresh-market, field-grown peppers are typically harvested by hand each week over the course of about a month (2). Most bell peppers are sold as mature green peppers, but growers receive a premium price for a limited amount of other fruit colors. This premium price reflects the fact that bright colored peppers are more costly to produce because field losses are higher, and yields are lower than those of bell peppers harvested at the mature green stage. Red bell peppers are the mature stage of most green bell peppers that have been allowed to ripen on the plant. Fruit sugar content increases as the pepper matures making most of the brighter colored peppers sweeter tasting than green peppers. Most bell pepper cultivars can be used in both processing and fresh-market sales making the bell pepper a dual-market product.

Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel) manufactures colored shade cloths, tradenamed ChromatiNet®, advertised as improving utilization of solar radiation by agricultural crops (3). Polysack claims this technology promotes differential stimulation of desirable physiological responses in plants, thus increasing the commercial value of crops. ChromatiNet® is advertised as an economical and environmentally friendly alternative to labor-intensive procedures, such as pruning and thinning, and the widespread use of growth regulators and other chemicals that most growers currently use. Growers should be able to control vegetative growth characteristics, such as leaf size, branch length, and plant height by using the proper ChromatiNet® color in production (3). Polysack further claims control of the rate of flowering and maturation with this product. This added control allows growers to manipulate maturation so their products can meet market demands.

ChromatiNet® Red Shade Net changes the solar radiant energy transmitted to plants by reducing the blue, green, and yellow spectrums and increasing the red and far-red spectrums (3). According to Polysack, plant development under red radiant energy increases leaf surface area, stems are longer and thicker, and total foliage volume is higher. Polysack claims ChromatiNet® Red Shade Net causes earlier flowering without decreasing flower quality. ChromatiNet® Grey Shade Net blocks infra-red radiant energy and distributes the remaining by refraction through the special crystalloid structure of the grey net filament. ChromatiNet® Pearl Shade Net diffuses direct solar radiation when it passes through the threads, causing the radiation to cover many more plant parts, especially the lower stems and leaves. This increases photosynthetic efficiency, accelerates growth, and improves product quality. The number of secondary branches is also increased by the diffused light in many plants, greatly benefiting stem and leaf production.

High tunnels are simplified growing systems that enhance crop growth, yield, and quality (6). High tunnels are nonpermanent, infield structures, lacking electrical service, automated ventilation, and permanent heating systems, though temporary heaters may be used during frosts, that resemble traditional polyethylene covered greenhouses, but is a completely different technology (7, 6). High tunnels consist of a pipe or other materials framework covered in a single layer of greenhouse-grade 4 mm (0.16 in) to 6 mm (0.24 in) polyethylene plastic while most traditional greenhouses use a double layer of plastic (1, 5). High tunnels are ventilated by manually rolling the side walls up and down with a roll bar that runs the length of the tunnel and depends on cross winds to provide ventilation, while a traditional greenhouse uses an automated ventilation system and fans to circulate air (7, 6).

High tunnels are much more economical than automated greenhouses that have higher capital cost and higher maintenance expenses (6). A high tunnel could be constructed in 1998 relatively inexpensively, at about $1.25 per 0.3048 m^2 (square foot). High tunnels are used for growing season extension in the spring and fall. Using season extension, crops can be planted earlier and fruit picked sooner allowing them to be sent to market sooner than crops in an outdoor cropping system. Disease control is another benefit of high tunnels. The plastic layer serves as a barrier against moisture and disease spores.

Stephens (4) grew the ornamental chili pepper, ‘Explosive Ember’, in New South Wales under no shade, or red, blue, or gray shade nets. After 8 weeks, the control had the best leaf color, but attracted the most insect pests. Blue produced the shortest plants. Red produced more branches and attracted fewer thrips or other insect pests than the other treatments. Even though red gave the best results, differences were not large enough for red shade cloth to be installed on a large scale at the researcher's facility. Gray produced the tallest plants, bushier plants than the control, and the poorest foliage color. Gray did not reduce pests significantly.

Stephens (4) also used 'Eclipse' ivy geranium [*Pelargonium peltatum* (L.) L´ Hér] with the same colored shade cloth treatments. The control produced the shortest plants and the shortest internodes. Blue produced the longest leaves in the study. Grey produced the longest internodes and wider leaves than the control, but the fewest branches, flowers, and buds. Red produced the tallest plants and the shortest leaves, but leaves were wider than the control. Red produced the most branches, flowers, and buds.

Shahak (5) compared commercially grown bell peppers under 30-40% black shade cloth to ones grown under red, yellow or pearl shade cloths in the Besor area of Israel. Colored shade nets produced 30-40% more fruit per plant than black. Marketable fruit was 20-30% higher under the colored nets than under black. Fruit size was similar across treatments. Fruit grown under colored nets was smaller than those grown under black shade cloth in August and September, but this trend reversed late in the harvest season. Red shade net produced better results than yellow or pearl. The objective of these studies was to determine the effects of various colored shade cloth on yield and grade of colored bell peppers grown in a high tunnel production system.

Materials and Methods

The 2007-2008 colored bell pepper study was conducted in a 9.8 m W × 29.3 m L × 5.5 m H (32 ft W × 96 ft L × 18 ft H) Farm-tek (Dyersville, IA) high tunnel at the Auburn University, E.V. Smith Research Center (Shorter, AL U.S.A. latitude: 32.394N. longitude: -85.916W.). It was positioned on a north/south longitudinal axis for the first study. Wiggle wire locks were attached 1.2 m (4 ft) above the base of the high tunnel to allow the sides to be rolled up for passive cooling. Red, blue, gray, or pearl ChromatiNet® [Polysack Plastic Industries, Ltd. (Nir-Yitzhak, Sufa, Israel)], black shade cloth at 30% light reduction, or no shade cloth were applied over Fi-Shock (Woodstream Corporation Lititz, PA) 1.23 m (4 ft) Step-In Fence Posts set on either side of two rows of peppers.

Seed propagated bell peppers ‘Stiletto’ and ‘Tequila’ (Siegers Seed Company, Holland, MI), were sown in 72 cell trays containing Pro-Mix (Premier Horticulture Inc., Quakertown, PA). The seedlings were fertilized at a rate of 100 ppm using a 20-4.4-16.6 (20-10-20 Peters Professional®, The Scotts Company LLC, Marysville, Ohio) when the first cotyledons appeared. Five-week-old seedlings were hardened off by watering lightly at first and then increasing the interval between waterings making sure they didn’t dry out. In the hardening off process plants were exposed to less than optimum growing temperatures no more than -15° C (5° F). Two weeks prior to transplant nitrogen fertilizer was withheld from the seedlings to finish the hardening off process. The seedlings were transplanted into raised beds 46 cm (18 in) wide and 20.3 cm (8 in) tall covered with white plastic (Pliant Corporation, Schaumburg, IL) on May 9, 2007. Each bed had one line of T-Tape® (T-Systems International, San Diego, CA) in the center and under the mulch that delivered 1.7 Lpm per 30.5 m of row (0.45 gpm per 100 ft of row). The soil type was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic typic Kanhapludults). No soil amendments were applied. There were six plants per 3.0 m (10 ft) plot of each variety spaced 45.72 cm (18 in) apart within the row, and three replications of each colored shade cloth treatment.

The sides of the high tunnel were rolled down and the zippered end covers were closed whenever cold weather was expected. If a hard freeze was expected, row cover was placed over the peppers. Weekly harvests began September 29, 2007 and ended January 7, 2008. Only fruit that had reached full mature color were harvested. Full mature color for the peppers was red for ‘Stiletto’ and purple for ‘Tequila’. Fruit was graded and counted as marketable or unmarketable. Marketable fruit was close to U.S. Fancy grade, 3 or 4 lobed, well developed with no blemishes, and able to stand up on their own. Unmarketable fruit was marketable fruit, but not as high a grade as marketable. Any fruit with damage was discarded, and was not included in the grading process. All fruit in each grade was weighed from each plot.

The 2008-2009 colored bell pepper experiment used the same methods as the first except as follows: The high tunnel was positioned on an east/west longitudinal axis at E.V. Smith. Seed of bell peppers ‘Magno’ and ‘Permit’, were purchased from Enza Zaden (Enkhuizen, Netherlands). Bell pepper seedlings were transplanted into raised beds covered with white plastic June 4, 2008. There were plants that were girdled by rodents shortly after transplant. Stand counts were used to take these plant deaths into account. Hero™ insecticide was sprayed at a rate of 10 mL/ 5.7 L (0.01 q/ 1.5 gal) on September 23, 2008 for stink bugs, grasshoppers, worms, and black widow spiders. The rodents were treated by placing six low-profile Tomcat (Motomco, Ltd., Madison, WI) bait stations with Rampage® (Motomco, Ltd., Madison, WI) bait in them around the high tunnel November 21, 2008. The zippered ends were never put on the high tunnel in this study, but row cover was applied during cold weather. Harvests began August 19, 2008, occurred approximately once a week, and ended January 15, 2009. Full mature color for the peppers was orange for ‘Magno’ and red for ‘Permit’.

In both experiments, data was analyzed using PROC GLIMMIX in SAS version 9.1.3 (SAS Institute, Cary, NC) to determine significances of the main effects and the interaction at $\alpha = 0.05$. The experimental design was a split-plot with shade treatments completely randomized in the main plots and bell pepper varieties in the sub-plots. The ANOVA normality assumption for bell pepper counts was checked using tests for normality statistics in PROC UNIVARIATE. Data were considered non-normal when the Shapiro-Wilk, the Kolmogorov-Smirnov, the Anderson-Darling, and the Cramér-von Mises tests were significant at $\alpha = 0.05$. Non-normal data were analyzed using either the Poisson or the negative binomial probability distribution depending on which distribution minimized the Pearson Chi-Square goodness of fit statistic. Mean comparisons were determined using Tukey's honestly significant difference test at $\alpha = 0.05$.

Results

In the first study, there was a bell pepper variety × shade cloth color interaction for marketable fruit number and weight and unmarketable fruit weight while only the main effects were significant for unmarketable fruit number (Table 4). In the first study, 'Stiletto' had the highest marketable fruit numbers with blue, pearl, and red shade and no shade. For 'Tequila', there were no differences in marketable fruit numbers among the shade cloth treatments. 'Tequila' had more unmarketable fruit than 'Stiletto', and both varieties had the highest unmarketable fruit numbers with black, blue, gray, and red shade and no shade. The highest marketable and unmarketable fruit weights for 'Stiletto' were with black and red shade, respectively, and for 'Tequila' were no shade and pearl shade, respectively. 'Stiletto' had higher marketable and unmarketable fruit weights than 'Tequila' with all shade treatments except unmarketable fruit weight with black shade.

In the second study, there were shade cloth color × harvest date and bell pepper variety × harvest date interactions for marketable fruit number and weight (Table 5). Marketable fruit numbers and weights were highest for both varieties in the second harvest, but decreased sharply thereafter. In the first two harvests, ‘Magno’ had higher marketable fruit numbers and weights than ‘Permit’. For the first harvest, both varieties produced the highest numbers of marketable fruit under red, gray, and no shade. For the second harvest, it was red shade. For the third harvest it was black shade. For the fourth and fifth harvests it was black and red shade. For the sixth harvest it was the same for all shade cloth colors. For the first harvest, both varieties had higher marketable fruit weights with red and grey shade. For the second harvest, it was red shade.

There were shade cloth color × harvest date, bell pepper variety × harvest date and shade cloth color × bell pepper variety interactions for unmarketable fruit number (Table 6). Unmarketable fruit numbers were generally highest for ‘Permit’ in the fifth harvest, second to last harvest, and the last harvest. Unmarketable fruit numbers were generally highest for ‘Magno’ in the second to last harvest. ‘Magno’ had higher unmarketable fruit numbers than ‘Permit’ in the first three, the sixth, and the next to last harvests. ‘Magno’ had higher unmarketable fruit numbers with no shade across all harvests, while ‘Permit’ showed no differences. There were bell pepper variety × harvest date and shade cloth color × bell pepper variety interactions for unmarketable fruit weight (Table 7). Unmarketable fruit weights were highest in the next to last harvest for ‘Magno’ and the last for ‘Permit’. ‘Magno’ had higher unmarketable fruit weights than ‘Permit’. Across all harvests, ‘Magno’ had the highest unmarketable fruit weights with no shade, and ‘Permit’ had the highest unmarketable fruit weights with red shade.

Discussion

Many factors likely contributed to the variability in response of the bell pepper varieties used in these studies to the shade treatments. In Shahak’s (5) study, red shade net produced better results than yellow or pearl, but Shahak doesn't discuss what varieties were used in the study. 'Tequila' and 'Magno' generally yielded more than 'Stiletto' and 'Permit'. Because of the variability among varieties, dates of harvest, and colored shade cloth treatments, we are unable to ascertain a definitive shade cloth treatment that would improve colored bell pepper yield in a high tunnel production system under all conditions. Further research needs to be done on the subject to reach a clearer conclusion. Shahak's (5) study had a definitive trend in which colored shade nets produced smaller fruit than those under black shade net did in the early part of the season (August and September) which reversed later in the season. There was no clear trend that encompassed the four bell pepper varieties pertaining to harvest dates and fruit weights between the two colored bell pepper studies performed at E.V. Smith. Temperatures were freezing or below 29 times during the growing season. However, fruit was harvestable in the high tunnel late into the production period (January 15, 2009), though in lower numbers and grade, showing how effective the high tunnel was in extending the growing season.

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Table 4. Effects of ChromatiNet® shade cloth colors and no shade on fruit yield of two bell pepper varieties in 2007-2008.

Shade cloth	Black	Blue	Gray	None	Pearl	Red
Variety			Marketable fruit number[z]			
'Stiletto'	2bB[y]	5aA	2bB	5aA	4bA	4aA
'Tequila'	5aA	5aA	5aA	5aA	6aA	6aA
			Unmarketable fruit number[x]			
Shade cloth	6A	4A	5A	6A	3B	8A
Variety	'Stiletto'	1B	'Tequila'	7A		
Variety			Marketable fruit weight (g)[z]			
'Stiletto'	276.1aA	235.8aB	174.3aC	245.5aB	236.9aB	243.4aB
'Tequila'	90.7bBC	94.8bB	96.6bB	104.1bA	82.6bC	85.0bC
Variety			Unmarketable fruit weight (g)[z]			
'Stiletto'	43.3bD	115.0aBC	103.3aCD	126.7aB	103.3aCD	171.0aA
'Tequila'	55.4aB	52.6bBC	50.2bC	54.2bBC	74.7bA	56.3bB

[z]Marketable fruit was well developed without blemishes and 3 to 4 lobes. The variety × shade cloth color interaction was significant, $\alpha = 0.05$. Average fruit number per variety per shade cloth treatment per plot. Average weight per variety per shade cloth treatment per plot.

[y]Least squares means. Mean separation within columns (lower case) and rows (upper case) using Tukey's test, $\alpha = 0.05$.

[x]Only the main effects were significant, $\alpha = 0.05$. Average fruit number per shade cloth treatment per plot. Average fruit number per variety per plot.

Table 5. ChromatiNet® shade cloth color and no shade effects on marketable fruit number and weight of two bell pepper varieties in 2008-2009.

Marketable fruit number[z]								
	Shade cloth color						Bell pepper varieties	
Harvest date	None	Black	Blue	Gray	Pearl	Red	'Magno'	'Permit'
8/19/2008[y]	2aAB[x]	1cB	1bB	2bAB	1bB	3bA	2bA	1bB
8/28/2008	3aD	5aC	4aD	7aB	4aD	9aA	7aA	4aB
9/4/2008	1bB	2bA	1bB	1cB	1bB	2bB	2cA	1bB
9/10/2008	1bB	2bA	1bB	1cB	1bB	3bA	2c	1b
9/18/2009	1bB	3bA	1bB	1cB	1bB	3bA	2c	1b
10/2/2008	0bNS	1c	1b	1c	1b	1c	1d	1c
Marketable fruit weight (g) [w]								
8/19/2008	0.2bBC	0.2bC	0.1bC	0.4bAB	0.2bC	0.5bA	0.4bA	0.2bB
8/28/2008	0.4aC	0.8aB	0.6aB	1.3aB	0.7aB	1.5aA	1.1aA	0.7aB
9/4/2008	0.0c	0.3b	0.1b	0.1c	0.2b	0.2c	0.2b	0.1b
9/10/2008	0.1c	0.3b	0.1b	0.2c	0.2b	0.4b	0.3b	0.2b
9/18/2009	0.0c	0.4b	0.1b	0.2c	0.2b	0.4b	0.3b	0.2b
10/2/2008	0.0c	0.2b	0.1b	0.1c	0.0b	0.1c	0.1c	0.1b

[z]There were shade cloth color × harvest date and bell pepper variety × harvest date interactions at $\alpha = 0.05$. Marketable fruit was well developed without blemishes and 3 to 4 lobes. Average fruit number per shade cloth treatment per harvest date per plot. Average fruit number per variety per harvest date per plot.

[y]Harvest dates, 10/9/2009, 10/16/2008, 10/23/2008, 10/30/2008, 11/6/2008, 11/13/2008, 11/19/2008, 12/4/2008, 12/11/2008, 12/18/2008, 1/6/2009, and 1/15/2009 were omitted. Marketable fruit numbers were 1 or 0, or 0.1 g or less for marketable fruit weight and were in the same Tukey category as those on 10/2/2008.

[x]Least squares means. Mean separations within columns (lower case) and within rows (upper case) using Tukey's test at $\alpha = 0.05$. NS is not significant.

[w]Average fruit weight per shade cloth treatment per harvest date per plot. Average fruit weight per variety per harvest date per plot.

Table 6. ChromatiNet® shade cloth color and no shade effects on unmarketable fruit number of two bell pepper varieties in 2008-2009. [z]

	Shade cloth color						Bell pepper varieties	
Harvest date	None	Black	Blue	Gray	Pearl	Red	'Magno'	'Permit'
8/19/2008	1d[y]	1c	1d	2c	0c	1c	2eA	0eB
8/28/2008	10bA	2cB	1dC	2cB	2cB	3cB	5cA	2dB
9/4/2008	8bA	6bB	4cB	3cC	6bB	8bAB	7cA	3dB
9/10/2008	8b	7b	8b	6b	9a	7b	9b	6b
9/18/2009	9b	8b	9b	7b	12a	11b	10b	9a
10/2/2008	12bA	5bB	12bA	8bA	10aA	8bAB	11bA	7bB
10/9/2009	3c	2c	2c	2c	2c	1c	3e	2d
10/16/2008	3c	2c	2c	3c	2c	3c	3e	2d
10/23/2008	3c	2c	2c	1c	2c	3c	2e	2d
10/30/2008	5c	4b	1c	4c	6b	6b	4d	5c
11/6/2008	5c	2c	2c	2c	1c	3c	2e	3d
11/13/2008	4c	3c	3c	1c	4b	6b	4d	3d
11/19/2008	6c	4b	5c	4c	2c	3c	4d	4c
12/4/2008	8b	5b	5c	3c	4b	7b	6c	5c
12/11/2008	4c	4b	2c	3c	4b	3c	4d	3d
12/18/2008	8b	7b	7b	7b	7b	8b	7c	7b
1/6/2009	17a	11a	16a	14a	13a	20a	20aA	10aB
1/15/2009	7cB	7bB	9bAB	14aA	13aAB	8bB	9b	11a
'Magno'	9aA	4B	5B	5B	7B	6B		
'Permit'	5b	4	5	4	4	6		

[z]There were shade cloth color × harvest date, bell pepper variety × harvest date, and shade cloth color × bell pepper variety interactions at $\alpha = 0.05$. Average fruit number per shade cloth treatment per harvest date per plot. Average fruit number per variety per harvest date per plot.

[y]Least squares means. Mean separations within columns (lower case) and within rows (upper case) using Tukey's test at $\alpha = 0.05$. Upper case letters absent within rows were not significant.

Table 7. ChromatiNet® shade cloth color and no shade effects on unmarketable fruit weight (g) of two bell pepper varieties in 2008-2009 .[z]

Harvest date	Bell pepper varieties: 'Magno'	Bell pepper varieties: 'Permit'	Shade cloth color	Bell pepper varieties: 'Magno'	Bell pepper varieties: 'Permit'
8/19/2008	0.2c[y]	0c	None	1.1a	0.7b
8/28/2008	0.6c	0.3c	Black	0.6b	0.7b
9/4/2008	1.0b	0.7b	Blue	0.7b	0.8b
9/10/2008	1.3b	1.0b	Gray	0.8b	0.7b
9/18/2009	1.4b	1.4b	Pearl	1.0b	0.6b
10/2/2008	1.5b	1.1b	Red	0.8bB	1.5aA
10/9/2009	0.4c	0.2c			
10/16/2008	0.3c	0.3c			
10/23/2008	0.2c	0.4b			
10/30/2008	0.6c	0.8b			
11/6/2008	0.3c	0.5b			
11/13/2008	0.6c	0.6b			
11/19/2008	0.5c	0.7b			
12/4/2008	0.9b	0.9b			
12/11/2008	0.5c	0.5b			
12/18/2008	1.0b	1.1b			
1/6/2009	2.7aA	1.4bB			
1/15/2009	0.9bA	3.0aB			

[z]There were bell pepper variety × harvest date and shade cloth color × bell pepper variety interactions at α = 0.05. Average fruit weight per variety per harvest date per plot. Average fruit weight per shade cloth treatment per variety per plot.
[y]Least squares means. Mean separations within columns (lower case) and within rows (upper case) using Tukey's test at α = 0.05. Upper case letters absent within rows were not significant.

Chapter IV

Final Discussion

The purpose of the Chapter 2 studies was to evaluate the effects of colored mulch on cut flower production in a high tunnel production system. In the first study, snapdragon (*Antirrhinum majus*) cultivars ‘Potomac Apple Blossom’, ‘Supreme Gold Yellow’, ‘Potomac Yellow’, ‘Potomac Orange’, and ‘Potomac Pink’ were planted in raised beds covered with red, white, or blue plastic mulch in a high tunnel. Stem length, stem diameter 30.48 cm [4 in] from the base, and inflorescence length was recorded for each plant at harvest. Blue mulch produced the longest stems for all cultivars except ‘Supreme Gold Yellow’. White mulch produced the longest stems for ‘Potomac Orange’. ‘Potomac Orange’ and ‘Supreme Gold Yellow’ produced the longest stems among the cultivars on blue mulch. White and bue mulch produced the thickest stems. ‘Potomac Yellow’ produced the thickest stems. White and blue plastic mulch produced the longest inflorescences. ‘Potomac Orange’, ‘Potomac Yellow’, and ‘Supreme Gold Yellow’ produced the longest inflorescences.

In the second study, snapdragons and dianthus (*Dianthus barbatus* interspecific) were evaluated on red, white, blue, black, or bare ground in a high tunnel production system. The snapdragons were analyzed the same as in the first study. Dianthus’ stem length and number of stems per plant were recorded. ‘Cool Bronze’ produced the longest stems on black, red, and white mulch. ‘Cool White’ produced the longest stems on black, blue, and red mulch. ‘Cool Bronze’ produced the thickest stem diameters. Black and blue plastic mulch produced the thickest stems. ‘Cool White’, ‘Cool Bronze’, and ‘Cool Rose’ had the same inflorescence lengths. There was no difference between black, blue, red, and white mulches for inflorescence lengths. In dianthus, black and blue mulch produced the most stems per plant and the longest stems. There were no differences in open flowers per stem rating among the mulch treatments. Blue and white plastic mulch produced the best cut flower characteristics in snapdragon when grown July to October. 'Potomac Orange' followed by 'Supreme Gold Yellow' followed by 'Potomac Yellow' yielded the best results for late summer snapdragon production. Black and blue plastic mulch produced the best cut flower characteristics in snapdragon and dianthus October to February. 'Cool Bronze' followed by 'Cool White' yielded the best results for late fall production of snapdragons.

The purpose of the research in Chapter 3 was to evaluate the application of ChromatiNet® shade cloth in a high tunnel production system for improving fruit yield of colored bell pepper (*Capsicum annuum*). In two studies, the bell pepper varieties 'Tequila' and 'Stiletto' in the first, and 'Magno' and 'Permit' in the second were grown under blue, gray, pearl, or red ChromatiNet® shade cloth, black shade cloth, or no shade cloth. In the first study, 'Stiletto' had the highest marketable fruit numbers with blue, pearl, and red shade and no shade. For 'Tequila', there were no differences in marketable fruit numbers among the shade cloth treatments. 'Tequila' had more unmarketable fruit than 'Stiletto', and both varieties had the highest unmarketable fruit numbers with black, blue, gray, and red shade and no shade. The highest marketable and unmarketable fruit weights for 'Stiletto' were with black and red shade, respectively, and for 'Tequila' were no shade and pearl shade, respectively. 'Stiletto' had higher marketable and unmarketable fruit weights than 'Tequila' with all shade treatments except unmarketable fruit weight with black shade.

In the second study, marketable fruit numbers and weights were highest for both varieties in the second harvest, but decreased sharply thereafter. In the first two harvests, ‘Magno’ had higher marketable fruit numbers and weights than ‘Permit’. For the first harvest, both varieties produced the highest numbers of marketable fruit under red, gray, and no shade. For the second harvest, it was red shade. For the third harvest it was black shade. For the fourth and fifth harvests it was black and red shade. For the sixth harvest it was the same for all shade cloth colors. For the first harvest, both varieties had higher marketable fruit weights with red and grey shade. For the second harvest, it was red shade. Unmarketable fruit numbers were generally highest for ‘Permit’ in the fifth harvest, second to last harvest, and the last harvest. Unmarketable fruit numbers were generally highest for ‘Magno’ in the second to last harvest. ‘Magno’ had higher unmarketable fruit numbers than ‘Permit’ in the first three, the sixth, and the next to last harvests. ‘Magno’ had higher unmarketable fruit numbers with no shade across all harvests, while ‘Permit’ showed no differences. Unmarketable fruit weights were highest in the next to last harvest for ‘Magno’ and the last for ‘Permit’. ‘Magno’ had higher unmarketable fruit weights than ‘Permit’. Across all harvests, ‘Magno’ had the highest unmarketable fruit weights with no shade, and ‘Permit’ had the highest unmarketable fruit weights with red shade.

Many factors likely contributed to the variability in response of the bell pepper varieties used in these studies to the shade treatments. ‘Tequila’ and ‘Magno’ generally yielded more than ‘Stiletto’ and ‘Permit’. Because of the variability among varieties, dates of harvest, and colored shade cloth treatments, we are unable to ascertain a definitive shade cloth treatment that would improve colored bell pepper yield in a high tunnel production system under all conditions. Further research needs to be done on the subject to reach a clearer conclusion. Shahak’s (5) study had a definitive trend in which colored shade nets produced smaller fruit than those under black shade net did in the early part of the season (August and September) which reversed later in the season. There was no clear trend that encompassed the four bell pepper varieties pertaining to harvest dates and fruit weights between the two colored bell pepper studies performed at E.V. Smith. Temperatures were freezing or below 29 times during the growing season. However, fruit was harvestable in the high tunnel late into the production period (January 15, 2009), though in lower numbers and grade, showing how effective the high tunnel was in extending the growing season.