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EFFECTS OF TEMPERATURE, LIGHT AND PLANT GROWTH REGULATORS ON FUEL-EFFICIENT POINSETTIA PRODUCTION

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EFFECTS OF TEMPERATURE, LIGHT AND PLANT GROWTH REGULATORS ON FUEL-EFFICIENT POINSETTIA PRODUCTION

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DEDICATION

To my loving family for all the support that kept me on track and my friends for the distractions that kept me sane through it all. To my dear Valerie Barasa your encouragement can't be measured. Nobody can feel the void you have left in my life. Rest in peace (November 22, 2010). I will live the dream until when we meet in heaven. To Lawrence Itela, God bless you abundantly for standing with me, you are such a true brother. Thank You.

ABSTRACT

Fuel-efficient poinsettia production has become an important topic in recent years due to increased fuel costs while wholesale prices have remained relatively unchanged. Fuel-efficient production results in energy saving, reduces costs associated with production and improves profitability of the poinsettia crop. Experiments were carried out to determine the effects of Fascination (a plant growth regulator), production temperature, light, and cold pre-harvest temperature on bract expansion, cyathia development, and retention for fuel-efficient poinsettia production.

The first experiment (Chapter 2) examined the effects of the plant growth regulator Fascination on bract expansion of poinsettias grown at relatively cool production temperatures. Poinsettia, (*Euphorbia pulcherrima* Willd. Ex Klotzsh), 'Freedom Early Red' and 'Prestige Early' plants were grown until first color was observed on the developing bracts and then moved to each of two different greenhouses with average daily temperatures of 15.5 ±0.33 or 18.0 ±0.74 °C. Fascination is a commercial plant growth regulator that contains a 1:1 ratio of the gibberellins (GA_{4+7}) and cytokinin (benzyladenine). Fascination was applied as a 5 or 10 ppm spray, and the applications were made either 2, 3, or 4 weeks after first color. Fascination improved bract size at 18 °C for 'Freedom Early Red' but not for 'Prestige Red'. Fascination increased plant height at 15.5 and 18 °C for both cultivars. Therefore, Fascination has the potential to increase bract size of 'Freedom Early Red' poinsettias that have been grown

at 15.5 °C; however, temperature will need to be increased to 18 °C to attain marketable bract size.

The second project (Chapter 3) included three experiments to determine the effect of temperature and light on poinsettia cyathia development. In the first experiment, 'Prestige Red' plants were grown at 18, 20, or 22 °C and three different shade levels (0, 50 or 75%) resulting in average daily light integrals (DLI) of 4.2, 2.1, or 1.1 $mol \cdot m^{-2} \cdot d^{-1}$, respectively, from the start of short days. The results showed that cyathia development increased as temperature or light increased. At 22 °C and 0% shade treatment, 70% of the shoots had cyathia that reached the nectar stage, while no shoots reached the nectar stage at 18 or 20 °C. No cyathia development occurred at 18 °C, regardless of light level. Similarly, no more than 10% of the shoots displayed cyathia development at 75% shade, regardless of temperature. In the second experiment, 'Prestige Red' plants were grown from the start of short days at 20 °C and under one of three daily light integral (DLI) treatments (0, 50 or 75% shade). The plants were moved between shade curtain treatments (0, 50 or 75%) at different dates in order to create nine different DLI treatments. The DLI treatments that had cumulative light levels of 42.9 to 56.1 $mol m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection successfully developed to the nectary gland stage. In contrast, DLI treatments that had cumulative light levels from 14.0 to 28.1 $mol\ m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection did not develop to the nectary gland stage. The 0% shade treatments had the largest cyathia at visible bud and were the only treatments that developed to the nectary gland stage. In the third

experiment, five poinsettia cultivars (‘Advent Red’, ‘Early Freedom Red’, ‘Jubilee Red’, ‘Prestige Red’, and ‘Prestige Early Red’) were moved at the start of visible bud to different greenhouses that had average daily set point temperatures of 15.5, 18, 20, or 22 °C. None of the cultivars reached the visible bud stage at 15.5 °C. Cyathia diameter increased as temperature increased from 18 to 22 °C. The rate of bud expansion was similar for plants grown at 20 and 22 ºC, but was slower at 18 °C. The time from visible bud to anthesis increased as temperature decreased, e.g., time from visible bud to anthesis took 15 days at 22 °C, 20 days at 20 °C and 25 days at 18 °C.

The third experiment (Chapter 4) examined the effect of pre-harvest temperatures on post-harvest longevity of flowering. Five poinsettia cultivars were grown at standard greenhouse production temperatures until anthesis of the primary cyathium. The plants were then moved to a greenhouse with 13 °C day and 9 °C night temperatures for 0, 1, 2, 3, or 4 weeks before they were placed into a simulated post-harvest environment consisting of average temperatures of 21 °C and a DLI of 0.5 mol $m^{-2}d^{-1}$. The dates of cyathia abscission were recorded for the primary and secondary cyathia. The best postharvest performance was observed on ‘Polar Bear’, where the primary cyathia lasted for 24, 23, 20, 19 or 17 days on plants held in the cold greenhouse for 0, 1, 2, 3 or 4 weeks, respectively, while the secondary cyathia lasted for 29, 25, 20, 19 and 17 days, respectively. The poorest postharvest performance was observed for ‘Prestige Red’, where the primary cyathium lasted for 12, 6, 3, or 0 days when held in the cold greenhouse for 0, 1, 2, 3, or 4 weeks, respectively. Assuming that 14 days of secondary

cyathia retention in the postharvest environment is considered to be acceptable, ‘Advent Red’ and ‘Polar Bear’ met this criterion following four weeks of pre-harvest, cold temperatures. ‘Polly’s Pink’ met this criterion following one week of cold pre-harvest temperature. ‘Prestige Red’ and ‘Freedom Early Red’ did not meet this criterion even when no cold pre-harvest environment was provided.

In conclusion, our first experiment, Fascination application rate of 10 ppm resulted in a significant increase in bract area for ‘Freedom Early Red’ if the application date was relatively late in bract development, e.g., 3 to 4 weeks after first color, and the air temperature was sufficiently warm, e.g., 18 °C. For ‘Prestige Red’, the trend was that bract area increased at 18 °C and 10 ppm Fascination; however these treatments were not statistically different from the control. Increases in ‘Freedom Early Red’ height were observed with the Fascination treatments that also positively increased bract area. Our results showed that Fascination can be used for fuel-efficient poinsettia production to increase plant height and bract expansion when the plants have experienced reduced bract size due to low temperature production. However, the efficacy of the application decreases at 15.5 °C, the greenhouse temperatures should be increased to allow for a more effective response to Fascination.

In the second experiment, cyathia development increased as temperature or light increased. At 22 °C and 0% shade treatment, 70% of the shoots had cyathia that reached the nectar stage, while no shoots reached the nectar stage at 18 or 20 °C. No cyathia development occurred at 18 °C, regardless of light level. Similarly, no more than 10% of

the shoots displayed cyathia development at 75% shade, regardless of temperature. The DLI treatments that had cumulative light levels of 42.9 to 56.1 $mol \cdot m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection successfully developed to the nectary gland stage. In contrast, DLI treatments that had cumulative light levels from 14.0 to 28.1 $mol\ m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection did not develop to the nectary gland stage. The 0% shade treatments had the largest cyathia at visible bud and were the only treatments that developed to the nectary gland stage. Cyathia diameter increased as temperature increased from 18 to 22 °C. The rate of bud expansion was similar for plants grown at 20 and 22 ºC, but was slower at 18 °C. The time from visible bud to anthesis increased as temperature decreased, e.g., time from visible bud to anthesis took 15 days at 22 °C, 20 days at 20 °C and 25 days at 18 °C.

In the third experiment, our research showed that following 2 to 4 weeks of exposing poinsettias to the cold pre-harvest treatment only two cultivars (‘Polar Bear’ and ‘Advent’) had secondary cyathia that persisted for 14 days in the postharvest environment. In contrast, ‘Prestige Red’, ‘Polly’s Pink’ and ‘Freedom Early Red’ performed relatively poorly in the postharvest environment. Demonstrating that cold pre-harvest treatment performance is cultivar-dependent. In conclusion, cold pre-harvest treatment is a potentially useful commercial technique in cultivars that have strong cyathia development and retention.

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CHAPTER ONE

LITERATURE REVIEW

History of poinsettia

The poinsettia, *Euphorbia pulcherrima* (Willd. Ex Klotzsh), belongs to the family Euphorbiaceae. It is native to southern Mexico near present day Taxco. The plant was cultivated by the Aztecs who called it Cuetlaxochitl. It served as a symbol of purity to the Indians due to its color. The showy red bracts were used to make a reddish dye and the latex was used to create medicine for fever (Shanks, 1980).

John Roberts Poinsett introduced the poinsettia to the United States in 1825. He found the plant growing in Taxco when he visited Mexico as the first United States Ambassador to Mexico. After having success with the plants in a greenhouse at his home in South Carolina, he sent plants to botanical gardens and friends. One of his friends sent a plant to John Bartram who was the first nurseryman to sell poinsettias. Many institutions started poinsettia-breeding programs in the mid 1950's (Dole and Wilkins, 2005). Towards the end of the 19th century, poinsettias were being grown commercially for Christmas sales, thus receiving its common name as the Christmas flower or Christmas star (Shanks, 1980).

Presently, poinsettia is the number one potted crop sold in the United States (Jerardo, 2002). They are grown for their large bracts that display brilliant colors. The center of

the inflorescence contains the cyathia, which are the true flowers. The cyathia can be round to elongate from which small red stamens are produced (Dole and Wilkins, 2005). Some of the colors for the poinsettias include: red, pink, and white.

Flower development in poinsettia

The poinsettia inflorescence consists of cluster of cyathia. The primary cyathium is the first flower to develop in the center of the inflorescence, and secondary cyathia are the three flowers that subtend the primary cyathium. Each cyathium is enveloped by a symmetrical, uniserate involucre that bears one nectary gland. A variable number of staminate flowers encircle a single pistillate flower in the center of the cyathium (Rao, 1971).

For floral initiation and development poinsettia requires short-days; thus it is considered a facultative short-day plant. Photoperiod triggers the flowering process, while temperature influences the time from flower initiation to anthesis. The rate of flower development increases as the average daily temperature increases from 16 to 22 °C. The optimal temperature for flower development occurs between 23-26 °C which means that plants progress toward flowering at the fastest possible rate at these temperatures. It should be noted that night temperatures exceeding 22 °C will delay flowering (Ecke et al 2004). As discussed earlier, poinsettias are native to Mexico and to better understand the environmental requirements of the poinsettias it is better to consider the conditions present during the plants evolution. The native location of poinsettia is at an elevation of 1780 meters above sea level with the coordinates 18° 32' North by 99°26'

West (AllRefer.com Gazetteer, 2004). The average monthly temperatures ranged from 23 to 27 °C and overnight lows from 8 to 13 °C. Based on civil twilight times the night length at Taxco ranges from 10 hours 59 minutes to 13 hours 1 minute as recorded by the US Naval observatory (2007). This relatively small change in day length most likely accounts for the range of critical night lengths seen in modern cultivars. This also explains why poinsettias respond so strongly to very small changes in photoperiod.

Effects of temperature on bract expansion

Average daily temperatures influence bract expansion. The largest bracts develop when average temperatures are maintained between 23-26 °C (Ecke, et al., 2004). Therefore, growing different cultivars in the same greenhouse can create challenges for managing the average temperature to promote proper bract expansion. Early-season cultivars may have fully expanded bracts, while the late-season cultivars may still have unexpanded bracts. If greenhouse temperatures are reduced because an early season cultivar is ready to go to market, then the bracts of a late season cultivar may not expand to an adequate size, delaying the market date.

High-energy costs have made growers consider growing poinsettias at reduced temperatures. Lower temperatures of 18-20 °C can work with relatively large-bracted, early-season cultivars, while this will not work well for small-bracted cultivars or for cultivars that are relatively slow to flower, i.e., mid- and late-season cultivars.

Effects of temperature on cyathia development and retention

Larson and Langhans (1963) first quantified the stages of floral initiation and development in poinsettias through microscopic observation of the apical meristem. In the vegetative state the apex was about 120 microns in length and flat in appearance. At initiation, the apex elongates to 135 microns and is visibly domed. Differentiation of floral bud primordia is visible 7 days later when the apex reaches 150 microns. The number of cyathia that develop per stem can be relatively low on some crops. This phenomenon is most often observed on large-bracted cultivars, such as 'Freedom', that are grown under relatively low light levels. The light level does not provide sufficient energy to support significant cyathia development. Large-bracted cultivars are more susceptible to poor cyathia development because the bracts create a large demand on the plant carbohydrate resources. This has been confirmed by removing the bracts as they develop, resulting in production of very high cyathia counts (Ecke et al, 2004). This suggests that conditions that limit bract expansion will allow for more cyathia development. Cooler finishing temperatures and plant growth regulators can produce a small, but desirable, reduction in bract size on large-bracted cultivars that also allows better cyathia development (Ecke, et al., 2004).

Low light levels and/or high forcing temperatures primarily cause premature cyathia drop. Water stress aggravates the problem. These conditions allow the carbohydrates status of the plant to become depleted, resulting in cyathia abscission (Ecke, et al., 2004). If poinsettias are grown at lower than optimal temperatures early in the production period, flower development may be delayed to later in the season when

cloudier weather and lower ambient light conditions predominate. It then becomes necessary to raise greenhouse temperatures to speed the flower development rate. As temperatures increase, plant food reserves are used at a faster rate due to higher respiration rates and the plants become more susceptible to premature cyathia drop (Ecke, et al., 2004, Miller and Heins, 1986).

Physiological limits of lower temperatures

Temperature controls the rate of plant development, including time to unfold a leaf and time to flower. As the average daily temperature (ADT) decreases, the rate of development decreases and a crop is increasingly delayed. In addition, if temperatures are at or below a species-specific base temperature, the developmental rate is zero and the plant stops developing. Poinsettias are tropical plants and are generally considered to be a cold-sensitive crop with a base temperature of 10 °C (Lopez, 2008). Poinsettia plants experience chilling injury when exposed to temperatures below 10 °C. It is not feasible to produce poinsettias at temperatures below 15.5 °C due to the excessively slow rate of flower development and limited bract expansion.

Potential savings when reducing greenhouse temperature set points

Energy costs in greenhouse production are higher than ever before, further reducing an already shrinking profit margin for poinsettia production. Cold temperature production saves energy and reduces costs associated with production and improves profitability (Ecke et al, 2006). Though cooler temperatures slow plant growth and can

require earlier planting, growers who cut back a few degrees late in the season could still save 20 to 40% on energy costs, depending on their location (Lopez, 2008). For example, a grower who uses natural gas to heat a ½-acre glass greenhouse in Toledo, Ohio, would spend about $18,200 to grow about 11,800 plants at the conventional temperature of 22 °C versus $13,500 if the temperature were 17 °C late in the season. A comparable greenhouse in New Hampshire, where heating oil is more common, would save about $7,300 from a $33,100 heating bill (Lopez, 2008).

In addition to increased energy cost savings, there are other benefits to producing poinsettias at cooler temperatures. For example, bract color is enhanced at cooler temperatures due to an accumulation of anthocyanins. Anthocyanins are a group of plant pigments responsible for colors ranging from red to violet and blue (Van Tunen & Mol 1991). These pigments accumulate in the vacuoles of epidermal cells and both their chroma and hue are dependent on external conditions, as well as on the pH in the vacuoles (Harborne & Grayer, 1998). Anthocyanins accumulate in epidermal vacuoles and blend with the plastid pigments to give various hues that vary with light exposure and night and day temperatures (Sachray et al., 2002). Temperature is one of the main external factors affecting anthocyanin accumulation in plant tissues, e.g., low temperatures increase, and elevated temperatures decrease anthocyanin concentration (Marousky, 1968; Zhong & Yoshinda, 1993; Oren-Shamir & Nissim-Levi, 1997; 1999; Zhang et al., 1997).

Factors that need to be considered when reducing greenhouse temperature

Cold-grow poinsettia production is not accomplished simply by turning the thermostat down (Ecke et. al, 2008). In order to produce a quality crop it is imperative growers follow certain cultural guidelines and choose from a list of cultivars proven to perform well in colder environments. Crop scheduling and cultivar selection are the most important decisions to make when cold-growing poinsettia.

Early-season cultivars are desirable for cold production. Colder finishing temperatures can cause a 1 to 3 week delay in finishing time. Those cultivars that initiate earlier and have shorter response times will finish within an acceptable amount of time to meet market demand even when flowering is delayed by cool production temperatures. The early-season cultivars, when grown cold, will perform like mid- to late-season cultivars (Ecke et al, 2008). The cultivars chosen should have good vigor to compensate for reduced temperatures. Cool temperatures slow down growth and development, therefore vigorous cultivars compensate for reduced temperatures. Since cooler temperatures reduce plant size, the crops may need to be planted 1-2 weeks earlier to allow for adequate vegetative growth prior to flower initiation in order to compensate for reduced vigor once temperatures are reduced (Lang, 2009).

Diseases, such as powdery mildew and *Botrytis*, favor cool temperatures, so a preventive fungicide program should be implemented (Lang, 2009). At cooler growing temperatures, plant metabolism and growth rate slow which affects nutrient and water uptake, therefore it is imperative to closely monitor pH and the electrical conductivity of

the growing media to maintain acceptable levels for healthy growth. Provision of good air circulation and adequate ventilation are necessary to the crops in order to reduce relative humidity, since cold greenhouse temperatures at night increase moisture condensation in the crop canopy which can lead to *Botrytis* problems when the condensation on the greenhouse glazing material drips onto the crop.

Use of benzyladenine and gibberellic acid to expand plant organs

Fascination is a plant growth regulator that contains a 1:1 ratio of the gibberellins (GA_{4+7}) and cytokinin [benzyladenine (BA)]. Cytokinins induce the following plant responses: 1) stimulation of cell division, 2) morphogenesis (shoot initiation/bud formation) in tissue culture, 3) lateral bud growth via release of apical dominance, 4) leaf expansion resulting from cell enlargement, and 5) initiation and promotion of the conversion of etioplasts to chloroplasts via stimulation of chlorophyll synthesis. Cytokinins are well-known for regulating meristematic activity of the shoot apex (Fosket and Short, 1973; Seidlova and Krekule, 1977), and also promote expansion of excised radish (*Raphanus sativus* L.cv. Crimson Giant) cotyledons (Howard and Witham, 1983).

Active gibberellins induce many physiological effects, each dependent on the type of gibberellin present as well as the plant species. Some of the physiological processes stimulated by gibberellins are: 1) stem elongation by stimulating cell elongation, 2) flowering in response to long days, 3) breaking seed dormancy in some plants that require stratification or light to induce germination, 4) enzyme production (α-amylase) in germinating cereal grains for mobilization of seed reserves, 5) inducing male

characteristics in dioecious flowers (sex expression), 6) parthenocarpy (seedless) fruit development, and 7) delayed senescence in leaves and citrus fruits (National Academic Service JISCMAIL, 2003).

Several researchers have reported combined BA and GA have a synergistic effect. The synergistic effect produced by two plant hormones working in combination is greater than the sum of the individual parts (Han, 1995; Franco and Han, 1997). Also, combined BA and GA induce lateral shoot formation when applied during active shoot growth in both apple and cherry (Cody et al., 1985; Elfving and Visser, 2005, 2006). Fascination has been effective in increasing stem length and bract size and counteracting early or excessive growth regulator application (Fausey, 2006). Previous reports (Blanchard et al., 2005; Faust et al., 2008, 2009; Runkle, 2007) describe Fascination applications increase poinsettia height and bract size while making bracts smoother in appearance.

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CHAPTER TWO

EFFECTS OF FASCINATION APPLICATION TIMING AND CONCENTRATION ON FUEL-EFFICIENT POINSETTIA PRODUCTION

Introduction

Poinsettias are grown from July through early December in greenhouses maintained at temperatures averaging 18 to 20 °C. Thus, to grow poinsettia crops considerable fuel consumption is necessary during periods of cold weather. High fuel costs have made poinsettia production more expensive resulting in reduced profit margins. So, there is considerable interest in growing poinsettias at average daily temperatures <18 °C; however, this can have negative consequences in regard to increased time to market, reduced bract size, and shorter plants.

Fascination is a plant growth regulator that contains a 1:1 ratio of gibberellins (GA_{4+7}) and cytokinin (benzyladenine). Cytokinin is well known for regulating meristematic activity of the shoot apex (Fosket and Short, 1973; Seidlova and Krekule, 1977). Also, cytokinin promotes expansion of excised radish (*Raphanus sativus* L. 'Crimson Giant') cotyledons (Howard and Witham, 1983). Gibberellins have been shown to promote stem elongation (Heins et al., 1996). Several researchers have reported synergistic effects with BA and GA combinations (Han, 1995; Franco and Han, 1997). Synergistic effect occurs when the added effect produced by two plant hormones working

in combination is greater than the sum of the individual parts. Previous research has shown that BA and GA combined induce shoot formation on the current shoots when applied during active shoot growth in both apple and cherry (Cody et al., 1985; Elfving and Visser, 2005, 2006).

While no work has been published in refereed journals on the role of Fascination in poinsettia production, there have been reports of its use in commercial trade journals. This work suggests that Fascination has been effective in commercial poinsettia production for increasing stem length and bract size. When applied during the vegetative phase, Fascination is used to increase plant height, while applications made during bract development are used to increase bract size, particularly in situations where bract expansion is poor due to excessive application of gibberellin-synthesis inhibitors (Faust, et al., 2008, 2009; Runkle, 2007). Fascination has been proposed as a potential tool for increasing bract expansion of poinsettias grown at relatively cool temperatures. This technique, if successful, could allow commercial growers to lower their production temperatures but still achieve acceptable market characteristics.

Therefore, the objective of this study was to determine the effectiveness of Fascination at promoting stem elongation and bract expansion on poinsettias grown at relatively low greenhouse temperatures. Treatments tested the effects of Fascination application timing and concentration at two temperatures.

Materials and Methods

Unrooted cuttings of poinsettia ('Freedom Early Red', and 'Prestige Early') were received from Paul Ecke de Guatemala and propagated in Oasis wedges (Smithers-Oasis North America, Kent, Ohio). Rooted cuttings were then transplanted into 15-cm diameter plastic containers containing Fafard 3B growing medium (Fafard, Anderson, SC) on 9-Sept. 2009 and pinched to five nodes on 23-Sept. 2009. Incandescent lamps were used for night-interruption lighting, which occurred from 10 p.m. to 2 a.m. each night from 16-Sept. to 21-Oct. 2010. Fertilization of the plant was done at each irrigation with water soluble fertilizer 15N-2.2P-12.5 K-5Ca-2 Mg (Scotts-Sierra Horticultural Product Co., Marysville, Ohio) supplying nitrogen at 300 ppm. The experiment was conducted in glass-glazed greenhouse located at Clemson University, South Carolina (34.68 $^{\circ}$N 82.84 $^{\circ}$W) equipped with fan and pad cooling.

One hundred and sixty-eight plants were grown at an average daily temperature of 22.6 ± 0.83 °C until the start of short days and at 20.0 ± 0.68 °C until first color was observed on the developing bracts. First color was defined as the stage in which green leaves visibly display red pigmentation. At the start of first color, 84 plants were moved to each of two different greenhouses with average daily temperatures of 15.5 ± 0.33 or 18.0 ± 0.74 °C. Fascination was applied as a 5 or 10 ppm spray along with Capsil, a wetting agent, at rate of 0.4 ppm. The applications were made two, three or four weeks after first color. A 2x3x2 factorial design plus untreated control was used to test the effects of temperature,

Fascination application timing, and Fascination concentration, respectively. Six plants per cultivar were used for each treatment.

A destructive harvest was conducted on individual plants when they were considered marketable, as a result the plants grown at 18 °C were harvested on 8-Jan., 2010 and plants grown at 15.5 °C were harvested on 15-Jan., 2010. Plant height was recorded from the top of the growing media to the tallest shoot tip. The two tallest stems per plant were harvested and stem length, transitional bract number, transitional bract area, true bract area, and total bract area were recorded for each. Bract area was recorded with a leaf area meter (LI-3000; LI-COR, Inc. Lincoln, Neb). Transitional bracts are defined as the green leaves attached to the stem that change to red as the plant matures. True bracts are the three bracts that occur at the top of the stem in a whorl subtending the cyathia and are red when first visible. Total bract area is the sum of the area of the true and transitional bracts. The date of first bract color and anthesis was recorded for each plant.

All data were analyzed using analysis of variance and mean separation was accomplished using Tukey's test at $P \leq 0.05$. Interactions between treatments were significant for plant height, stem length, true bract area, transitional bract area, and total bract area (Tables 2.3 and 2.4).

Results and Discussion

Cultivar, Fascination concentration, application timing, and temperature significantly affected plant height and bract area (Table 2.3). In general, the trend was for increased height and increased bract area as temperature or Fascination concentration increased. Trends for application timing were not consistent.

Significant plant height and stem length responses to the Fascination rate of 10 ppm applied 2 or 3 weeks after first color were observed on 'Freedom Early Red' grown at 15.5 °C. Fascination rates of 10 ppm applied three weeks after first color to 'Freedom Early Red' plants grown at18.0 °C resulted in increased final plant height and stem length. Fascination rate of 10 ppm applied 2 or 3 weeks after first color showed an increase in plant height and stem length of 'Prestige Red' grown at 15.5 °C. At 18.0°C, Fascination rate of 5 or 10 ppm applied 3 weeks after first color to 'Prestige Red' resulted in an increase in final plant height and stem length. There was no treatment effect on bract area at 15.5 °C for 'Freedom Early Red'. Fascination at the rate of 5 or 10 ppm applied four weeks after first color to plants grown at 18.0 °C increased bract size of 'Freedom Early Red'. Similarly, Fascination at the rate of 10 ppm applied three weeks after first color to plants grown at 18.0 °C increased bract size of 'Freedom Early Red' (Table 2.1). There was no significant treatment effect on bract area at 15.5 °C for 'Prestige Red'. Fascination treatments did not significantly influence true bract, transitional bract, or total bract area at the two temperatures that were used in the experiment for 'Prestige Red' (Table 2.2).

The Fascination application rate of 10 ppm resulted in a significant increase in bract area for 'Freedom Early Red' if the application date was relatively late in bract development, e.g., 3 to 4 weeks after first color, and the air temperature was sufficiently warm, e.g., 18 °C. For 'Prestige Red', the trend was that bract area increased at 18 °C and 10 ppm Fascination; however these treatments were not statistically different from the control. Increases in 'Freedom Early Red' height were observed with the Fascination treatments that also positively increased bract area. This increase in height can be beneficial or detrimental depending on crop height at the time of application.

Results from this study indicate that Fascination can be used to increase plant height is in agreement with previous research (Blanchard et al., 2005; Runkle, 2007). The typical Fascination concentration used for height increase is 3 to 6 ppm (Runkle, 2007). In this study, higher rates (5 to 10 ppm) of Fascination were used to compensate for the lower efficacy that was expected at the cooler experimental temperatures.

Theoretically, Fascination applications made earlier during flowering, e.g., two weeks after first color, would have a greater potential impact on stem elongation since the application date would occur while the plants were still elongating rapidly. Week 2 applications might occur too early in bract development to impact bract area. In contrast, later applications, e.g., four weeks after first color, would occur when there is less stem elongation potential and greater bract expansion potential. However, these trends were not evident in this study with the exception of later application of 10 ppm Fascination at 18 °C on 'Freedom Early Red' which resulted in significantly larger bract area.

Our results showed that Fascination can be used for fuel-efficient poinsettia production to increase plant height and bract expansion when the plants have experienced reduced bract size due to low temperature production. However, the efficacy of the application decreases at 15.5 °C, the greenhouse temperatures should be increased to allow for a more effective response to Fascination.

Table 2.1. Effect of Fascination timing and concentration at two temperatures on plant height, stem length, leaf area, true bract area, transitional bract area, and total bract area of poinsettia 'Freedom Early Red'. Data were collected when the individual plants reached anthesis.

	Fascination application						
Temp (°C)	Timing (wk)	Concentration (ppm)	Plant height (cm)	Stem length (cm)	True bract area (cm^2)	Transitional bract area (cm^2)	Total bract area (cm^2)
15.5	0	0	25.4 d	13.4 c	47.8 d	226.8 d	274.6 e
	2	5	27.3 bcd	14.6 bc	57.5 cd	260.8 cd	310.1 cde
		10	30.9 abc	17.6 ab	64.2 cd	252.6 cd	316.8 cde
	3	5	29.3 bcd	16.2 abc	66.3 bcd	289.1 cd	355.4 cde
		10	31.3 ab	17.8 ab	48.8 d	235.6 d	284.4 de
	4	5	28.4 bcd	15.4 bc	62.5 bcd	274.2 cd	336.7 cde
		10	28.7 bcd	16.9 abc	76.4 bc	336.3 bcd	412.7 bcde
18	0	0	26.7 cd	14.4 bc	53.2 cd	275.2 cd	328.4 cde
	2	5	30.5 abc	17.1 abc	87.1 b	336.7 bcd	423.8 bcd

	10	30.0 abc	16.7 abc	73.8 bcd	368.3 abc	442.1 bc
3	5	30.5 abc	18.0 ab	77.5 bc	352.1 abcd	429.6 bc
	10	33.7 a	19.4 a	78.5 bc	430.8 ab	509.4 ab
4	5	29.3 bcd	16.8 abc	117.9 a	420.2 ab	538.1 ab
	10	31.0 ab	17.6 ab	142.4 a	474.8 a	617.2 a

Means within columns depicted with different letters are significantly different using Tukey (HSD at α=0.05).

Table 2.2. Effect of Fascination timing and concentration at two temperatures on plant height, stem length, leaf area, true bract area, transitional bracts area, and total bract area of poinsettia 'Prestige Red'. Data were collected when the individual plants reached anthesis

	Fascination application						
Temp (°C)	Timing (Wk)	Concentration (ppm)	Plant height (cm)	Stem length (cm)	True bract area (cm^2)	Transitional bract area (cm^2)	Total bract area (cm^2)
15.5	0	0	20.0 e	12.2 c	68.6 a	192.9 a	261.5 a
	2	5	22.3 de	14.1 bc	82.2 a	223.0 a	305.2 a
		10	29.6 ab	16.9 ab	73.3 a	232.0 a	305.2 a
	3	5	28.5 bc	15.7 bc	97.2 a	216.3 a	313.4 a
		10	30.0 ab	16.6 ab	87.1 a	220.0 a	307.1 a
	4	5	28.5 bc	15.7 bc	83.4 a	270.3 a	353.7 a
		10	28.2 bc	16.0 abc	97.4 a	239.1 a	336.5 a
18	0	0	25.1 cd	13.6 bc	72.2 a	222.4 a	294.6 a

2	5	28.7 abc	16.9 ab	87.2 a	250.2 a	337.4 a
	10	31.0 ab	16.9 ab	86.8 a	281.5 a	368.2 a
3	5	30.3 ab	17.5 ab	89.1 a	285.5 a	374.6 a
	10	32.4 a	19.6 a	91.0 a	273.1 a	364.1 a
4	5	28.0 bc	15.8 abc	83.8 a	228.4 a	312.2 a
	10	27.7 bc	15.5 bc	87.9 a	295.2 a	383.1 a

Means within columns depicted with different letters are significantly different using Tukey (HSD at α=0.05).

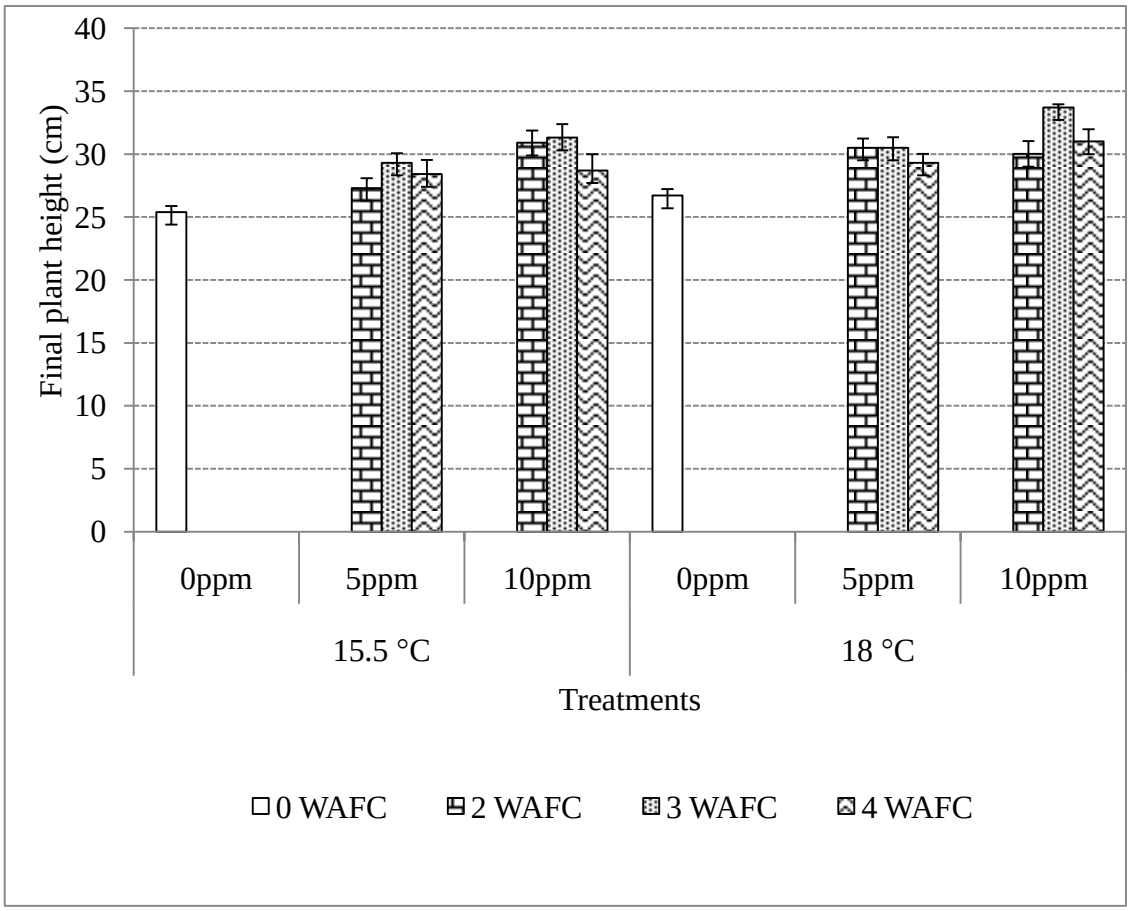
Table 2.3. Analysis of variance (ANOVA) table for effects of Fascination on plant height.

Source	Degrees of freedom	p-value
Temperature	1	0.0253
Weeks	3	0.0002
Concentration	2	< 0.0001
Cultivar	1	0.0070
Temperature*Weeks	3	0.2246
Temperature*Weeks*Concentration	6	0.9937
Temperature*Weeks*Concentration*Cultivar	6	0.0199

Table 2.4. Analysis of variance (ANOVA) table for effects of Fascination on bract area.

Source	Degrees of freedom	p-value
Temperature	1	< 0.0001
Weeks	3	<0.0001
Concentration	2	0.0331
Cultivar	1	<0.0001
Temperature*weeks	3	0.8601
Temperature*weeks*concentration	6	0.5364
Temperature*weeks*concentration*cultivar	6	0.0456

A.


40
35
30
25
20
15
10
5
0
Final plant height (cm)
0ppm
5ppm
10ppm
0ppm
5ppm
10ppm
15.5 °C
18 °C
Treatments
0 WAFC
2 WAFC
3 WAFC
4 WAFC

B.

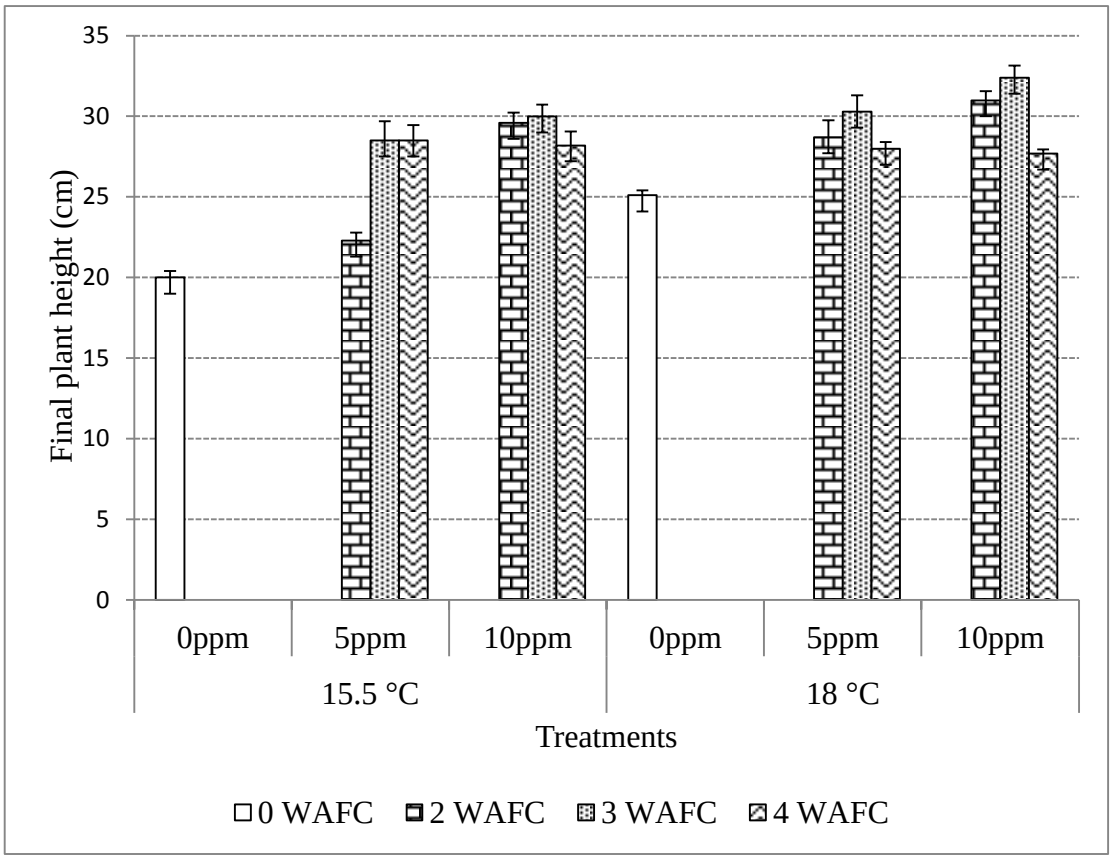
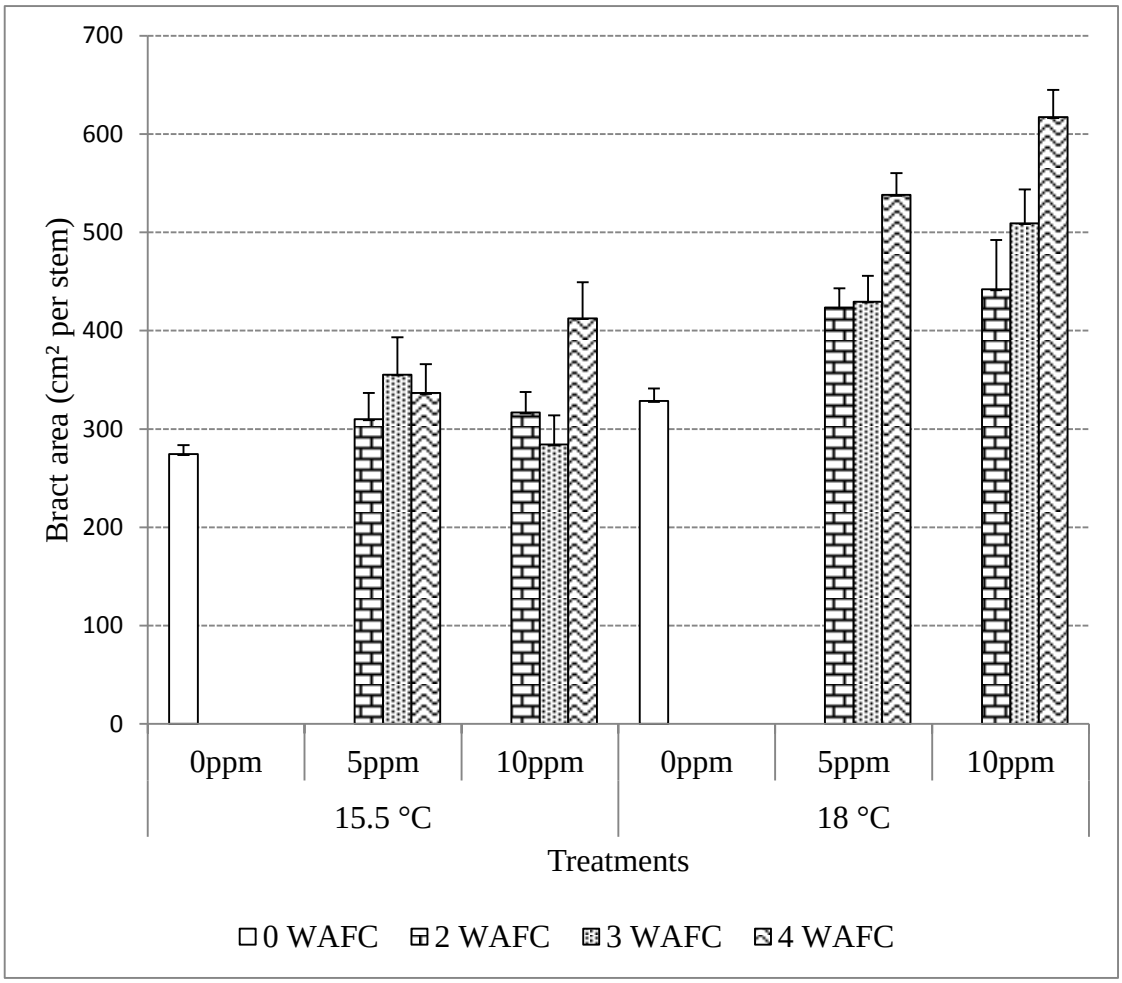


Fig. 2.1 Effects of Fascination at rates of 0, 5 or 10 ppm applied 0, 2, 3, or 4 weeks after first color (WAFC) on final plant height of poinsettia (A). 'Freedom Early Red' and (B). 'Prestige Red'. Error bars represent standard error of the mean. Six plants per treatment were used.

A.


700
600
500
400
300
200
100
0
Bract area (cm² per stem)
0ppm
5ppm
10ppm
0ppm
5ppm
10ppm
15.5 °C
18 °C
Treatments
0 WAFC
2 WAFC
3 WAFC
4 WAFC

B.

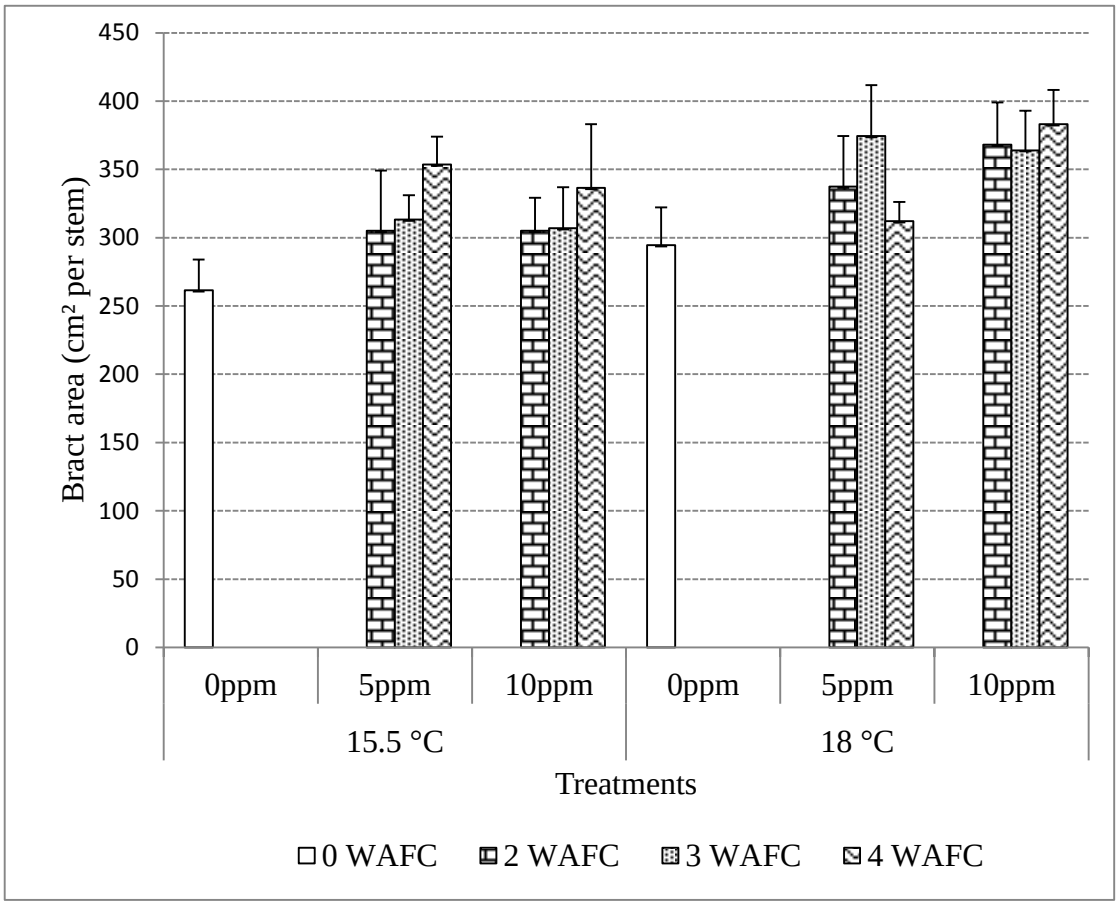


Fig. 2.2 Effects of Fascination at rates of 0, 5 or 10 ppm applied 0, 2, 3, or 4 weeks after first color (WAFC) on bract area of poinsettia (A). 'Freedom Early Red' and (B). 'Prestige Red'. Error bars represent standard error of the mean. Six plants per treatment were used.

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CHAPTER THREE

EFFECT OF TEMPERATURE AND DAILY LIGHT INTEGRAL ON POINSETTIA CYATHIA DEVELOPMENT

Introduction

Poinsettia marketing depends on both bract and cyathia presentation. While bracts are the most showy portion of the inflorescence, the cyathia are important indicators of crop 'freshness' as cyathia eventually abscise while plants are maintained in a low light postharvest environment. Previous research has focused on the factors that affect cyathia abscission in the postharvest environment. Moe et al. (1992) showed that increasing light levels during the cultivation period resulted in a significant reduction of cyathia abscission in the postharvest environment. Moe et al. (2006) reported that cyathia abscission differed amongst cultivars with 'Millennium' having a better ability to retain cyathia than 'Lilo'. A combination of high night temperatures (21°C or higher) and low light intensities have been shown to increase premature cyathia abscission due to an inadequate supply of carbohydrates (Miller and Heins, 1986).

In recent years, commercial growers are producing poinsettias at cooler temperatures due to the relatively high price of fuel. Poor cyathia development has appeared to increase with cooler production temperatures. Most previous work has focused on cyathia abscission, not development; therefore, the objectives of this study

were to determine the effects of production temperature and light on cyathia development in the greenhouse environment.

Materials and Methods

General procedures

Unrooted poinsettia cuttings were received from Paul Ecke de Guatemala and propagated in Oasis wedges (Smithers-Oasis North America, Kent, Ohio). They were then transplanted into 15-cm diameter plastic pots containing Fafard 3B growing medium (Fafard, Anderson, SC) on 9-Sept. 2009 and pinched to five nodes on 23-Sept. 2009. Incandescent lamps were used for night-interruption lighting, which occurred from 10 p.m. to 2 a.m. each night from 16-Sept. to 21-Oct. 2010. Plants were fertilized at each irrigation with water soluble fertilizer 15N-2.2P-12.5K-5Ca-2Mg (Scotts- Sierra Horticultural Product Co. Marysville, Ohio) supplying nitrogen at 300 ppm. The experiment was conducted in glass-glazed greenhouse located in Clemson University, South Carolina (34.68 $^{\circ}$N 82.84 $^{\circ}$W) equipped with fan and pad cooling.

Experiment 1. Effect of temperature and light on cyathia development

Forty-five plants were grown at the average daily temperature of 22.6 °C until the start of short days when they were moved to three different greenhouses with average temperatures set-points of 18.0, 20.0, and 22.0 °C. Within each of the three greenhouses, shade curtains were used to provide 50 or 75% shade on the benches in addition to an ambient light treatment. The resulting average daily light integrals (DLI) of 4.2, 2.1, or

1.1 $mol \cdot m^{-2} \cdot d^{-1}$ were provided for the ambient light, 50 and 75% shade treatments, respectively. Ambient DLI was measured at canopy height with a data logger (Watchdog Data logger model 305, Spectrum Technologies, Inc, Plainfield, Illinois) and the remaining light treatments DLIs were calculated based on the transmission percentage of the shade curtains. Five plants were used for each DLI x temperature treatment.

Cyathia development was defined by four stages: visible bud, nectary gland, anthesis, and nectar. The visible bud stage was defined as the time when the primary bracts unfold from the apex, so there was no obstruction from seeing the complete diameter of the bud when viewed directly overhead. The nectary gland stage occurred when the gland that secretes nectar clearly visible.

A. Visible bud stage

B. Nectary gland stage

C. Anthesis stage

D. Nectar stage

Fig. 3.1. Four stages of cyathia development: A. Visible bud stage occurs when the first cyathium is visible to the eye without aid of a hand lens. B. Nectary gland stage is defined as when the gland that secretes nectar is clearly visible. C. Anthesis refers to the first visible pollen shed on the primary cyathium. D. Nectar stage is defined as the time when nectar is secreted from the nectary gland.

The primary cyathium typically lacks a nectary gland, so this stage was recorded on the secondary cyathia. Anthesis was defined when pollen was visible on the primary

cyathium. The primary cyathium is the first flower to develop in the center of the inflorescence, and secondary cyathia are the three flowers that subtend the primary cyathium. The nectar stage was defined as the time when nectar was secreted from the nectary gland. The dates of cyathia reaching each individual stage were recorded for each plant. Two shoots per plant were selected for data collection.

Experiment 2. Effect of DLI timing on cyathia development

At the start of short days, fifty-four plants were grown at an average temperature of 20 °C and were placed under one of three DLI treatments (0, 50, or 75% shade). The plants were moved between different shade curtains during the experiment in order to create nine DLI treatments. The following abbreviations were used to describe the treatments: each H (high) represents two weeks of ambient light, each M (medium) represents two weeks of 50% shade, and each L (low) represents two weeks of 75% shade. Four letters are used to describe each treatment since the experiment took eight weeks. The following are the nine DLI treatments: 1) HHHH, eight weeks of ambient light, 2) MMMM eight weeks of 50% shade, 3) LLLL, eight weeks of 75% shade, 4) MMHH, four weeks of 50% shade followed by four weeks of ambient light) 5. HMMH, two weeks of ambient light followed by four weeks of 50% shade followed by two weeks of ambient light, 6) HHMM, four weeks of ambient light followed by four weeks of 50% shade, 7) LLHH, four weeks of 75% shade followed by four weeks of ambient light, 8) HLLH, two weeks of ambient light followed by four weeks of 75% shade and then two

weeks of ambient light, and 9) HHLL, four weeks ambient and four weeks of 75% shade. These treatments made up a 3 x 3 factorial design, with five plants per treatment.

Table 3.1 shows the weekly DLI provided over the course of the experiment for each of the nine treatments. Five plants were used and the two tallest stems per plant were selected for data collection. The date of each stage of cyathia development was recorded daily for each plant.

Experiment 3. Effect of temperature on primary cyathia expansion

At the start of visible bud development, one hundred plants (20 plants per cultivar) were moved into each of four different greenhouses with average temperature set points of 15.5, 18.0, 20.0, or 22.0 °C. Five cultivars (Jubilee Red, Advent Red, Freedom Early Red, Prestige Earl Red, and Prestige Red) were used. Each plant was thinned to 3 shoots per stem at the start of short days on 21-Oct. 2009. Bud diameter of the primary cyathium was recorded weekly with digital calipers (Absolute Digimatic Caliper, Mitutoyo Corp, Japan) from the visible bud stage through anthesis.

Results

Expt. 1. At 18°C, no cyathia development was observed on 'Prestige Red'. When greenhouse temperatures were 20 °C, cyathia only reached the visible bud stage in the 50% shade treatment, and the cyathia failed to develop any further; the plants in the 0% shade treatment reached anthesis but did not produce nectar. At 22 °C, 70% of shoots at

the 0% shade treatment reached the nectar stage, while only 10% shoots of the 50 and 75% shade treatments reached the anthesis stage (Table 3.2).

Expt. 2. Cyathia development generally was better for plants that received two or more weeks of ambient light during their final stages of development. In contrast, no cyathia development occurred when plants were grown with 50 and 75% shade cloth during their final stages of development. The DLI treatments (HHHH, MMHH, HMMH and LLHH) had cumulative light levels of 56.1, 47.3, 56.1 and 42.9 $mol \cdot m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection. These treatments developed to the nectary gland stage. In contrast, DLI treatments (MMMM, HHMM, HHLL and LLLL) that had cumulative light levels of 28.1, 28.1, 14.0 and 14.0 $mol \cdot m^{-2} \cdot d^{-1}$ during the two weeks preceding data collection did not develop to the nectary gland stage (Table 3.3).

Expt. 3. None of the cultivars reached the visible bud stage when grown at 15.5 °C (Figs. 3.2 and 3.3). 'Advent Red' was the only cultivar that reached all four stages of cyathia development at temperatures of 18, 20 or 22 °C (Fig. 3.2.). 'Prestige Early Red' grown at 22 °C reached the visible bud and nectary gland stage of cyathia development (Fig. 3.2). Cyathia diameter at visible bud was affected by temperature from the start of short days, e.g., cyathia diameter increased as temperature increased. The rate of bud expansion was similar for plants grown at 20 and 22 °C, but was slower at 18 °C (Fig. 3.2.). The time from visible bud to anthesis increased as temperature decreased. For instance, time from visible bud to anthesis took 15 days at 22 °C, 20 days

at 20 °C and 25 days at 18 °C. Interestingly, the visible buds developed at 22 °C were larger than cyathia shedding pollen at 18 °C (Fig. 3.2).

Discussion

Results from this study indicate that temperature and light strongly impact cyathia development. Our research supports previous reports that the rate of plant development is influenced primarily by temperature and that flower development increased as temperature increased (Roberts and Summerfield, 1987; Whitman et al., 1997 and Yuan et al., 1998). Similarly, low light levels can delay the developmental rate by limiting the supply of photosynthates (Faust and Heins, 1993; Volk and Bugbee, 1991). High DLIs increase biomass accumulation, hasten development, and improve plant quality in many floricultural crops (Kaczperski et al., 1991).

Our research showed that cyathia developed as temperature and light increased. Previous research (Kaczperski et al., 1991; White and Warrington, 1988) reported that plant developmental rate increases as DLI increases until a threshold was reached; above that threshold, the effect of DLI on developmental rate is less and/or not significant. The results of this study showed that DLI is more critical during the final weeks of cyathia development than the DLI in the weeks immediately following the start of short days. The DLI treatments without shade cloth during the last weeks of cyathia development were the only treatments that developed to the nectary gland stage.

In summary, this study demonstrates that both temperature and DLI influence growth and development in cyathia development, but responses may vary, depending on the cultivar. We concluded that fuel-efficient production is only possible for cultivars that develop well at cool temperatures. Therefore, cultivar selection is critical.

Table 3.1. Weekly mean daily light integral (DLI) for each of the nine DLI treatments. The following abbreviations were used to describe the treatments: each H (high) represents two weeks of ambient light, each M (medium) represents two weeks of 50% shade, and each L (low) represents two weeks of 75% shade. Four letters are used to describe each treatment since the experiment took eight weeks. The nine DLI treatments are 1) HHHH, eight weeks of ambient light; 2) MMMM eight weeks of 50% shade; 3) LLLL, eight weeks of 75% shade; 4) MMHH, four weeks of 50% shade followed by four weeks of ambient light; 5) HMMH, two weeks of ambient light followed by four weeks of 50% shade and then followed by two weeks of ambient light; 6) HHMM, four weeks of ambient light followed by four weeks of 50% shade; 7) LLHH, four weeks of 75% shade followed by four weeks of ambient light; 8) HLLH, two weeks of ambient light followed by four weeks of 75% shade and then two weeks of ambient light; and 9) HHLL, four weeks ambient and four weeks of 75% shade.

	Week number							
DLI treatment	1	2	3	4	5	6	7	8
HHHH	4.2	5.4	3.6	2.8	2.9	2.8	5.3	4.9
MMMM	2.1	2.7	1.8	1.4	1.5	1.4	2.6	2.4
MMHH	2.1	2.7	1.8	1.4	2.9	2.8	5.3	4.9
HMMH	4.2	5.4	1.8	1.4	1.5	1.4	5.3	4.9
HHMM	4.2	5.4	3.6	2.8	1.5	1.4	2.6	2.4

LLLL	1.1	1.3	0.9	0.7	0.7	0.7	1.3	1.2
LLHH	1.1	1.3	0.9	0.7	2.9	2.8	5.3	4.9
HLLH	4.2	5.4	0.9	0.7	0.7	0.7	5.3	4.9
HHLL	4.2	5.4	3.6	2.8	0.7	0.7	1.3	1.2

Table 3.2. Effects of temperature and light on the percentage of shoots that reached each of the four individual stages of cyathia development of poinsettia ‘Prestige Red’.

Stage of cyathia development	Shade (%)	Temperature (°C)		
		18	20	22
Visible bud	0	0 d	100 a	100 a
	50	0 d	100 a	80 b
	75	0 d	0 d	10 c
Nectary gland	0	0 d	100 a	90 b
	50	0 d	0 d	10 c
	75	0 d	0 d	10 c
Anthesis	0	0 d	100 a	90 b
	50	0 d	0 d	10 c
	75	0 d	0 d	10 c
Nectar	0	0 b	0 b	70 a
	50	0 b	0 b	0 b

75	0 b	0 b	0 b

Means depicted within stages of cyathia development with letters indicating significant differences using Tukey's test at $p \leq 0.05$.

Table 3.3. Cyathia diameter at two stages of development for each of the nine daily light integral (DLI) treatments described in Table 3.1.

DLI treatment	Cyathia diameter (mm)	
	Visible bud stage	Nectary gland stage
HHHH	3.3 a	3.7 a
MMMM	3.0 b	-
MMHH	3.5 a	4.0 a
HMMH	3.4 a	3.6 a
HHMM	2.5 b	-
LLLL	3.1 b	-
LLHH	3.6 a	3.6 a
HLLH	3.4 a	3.7 a
HHLL	2.3 b	-

Means within columns depicted with different letters are significantly different using Tukey's test at $p \leq 0.05$.

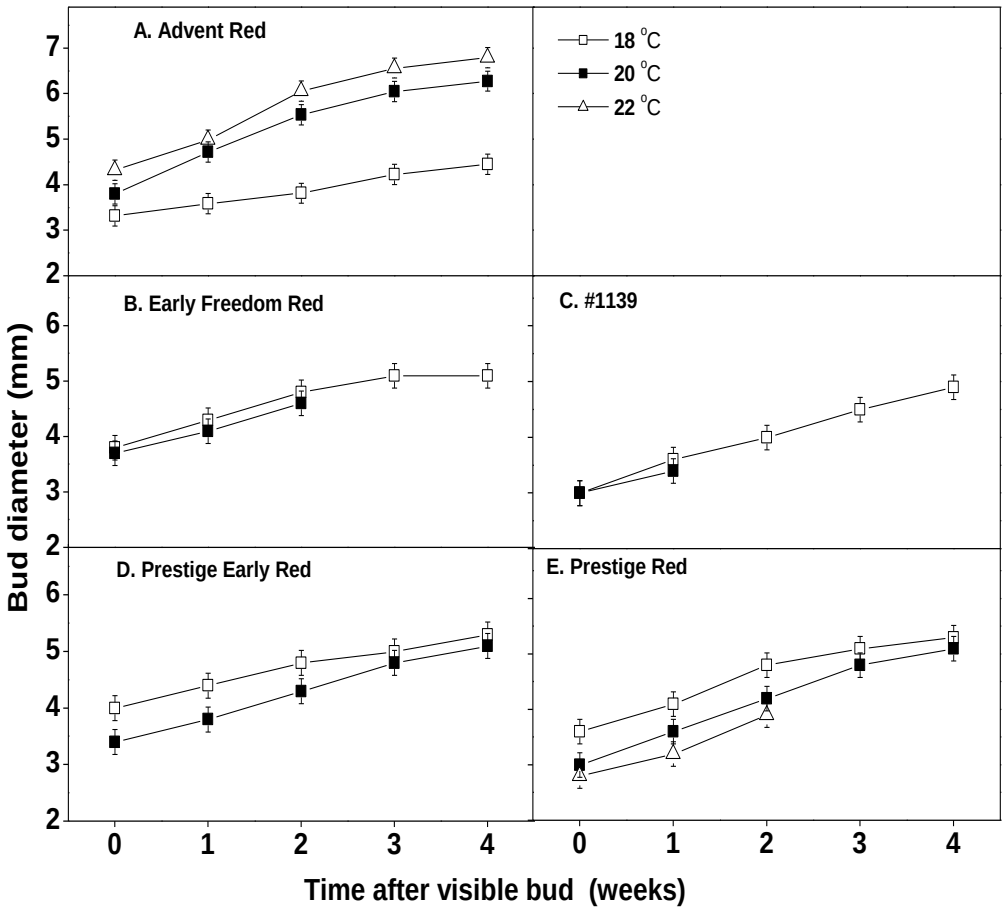

Fig. 3.2. The effect of temperature on primary cyathia expansion from visible bud onward for five poinsettia cultivars: (A) 'Advent Red', (B) 'Early Freedom Red', (C) 'Jubilee Red' (1139), (D) 'Prestige Early Red', (E) 'Prestige Red'. No data are shown for plants grown at 15.5 °C due to the lack of cyathia development.

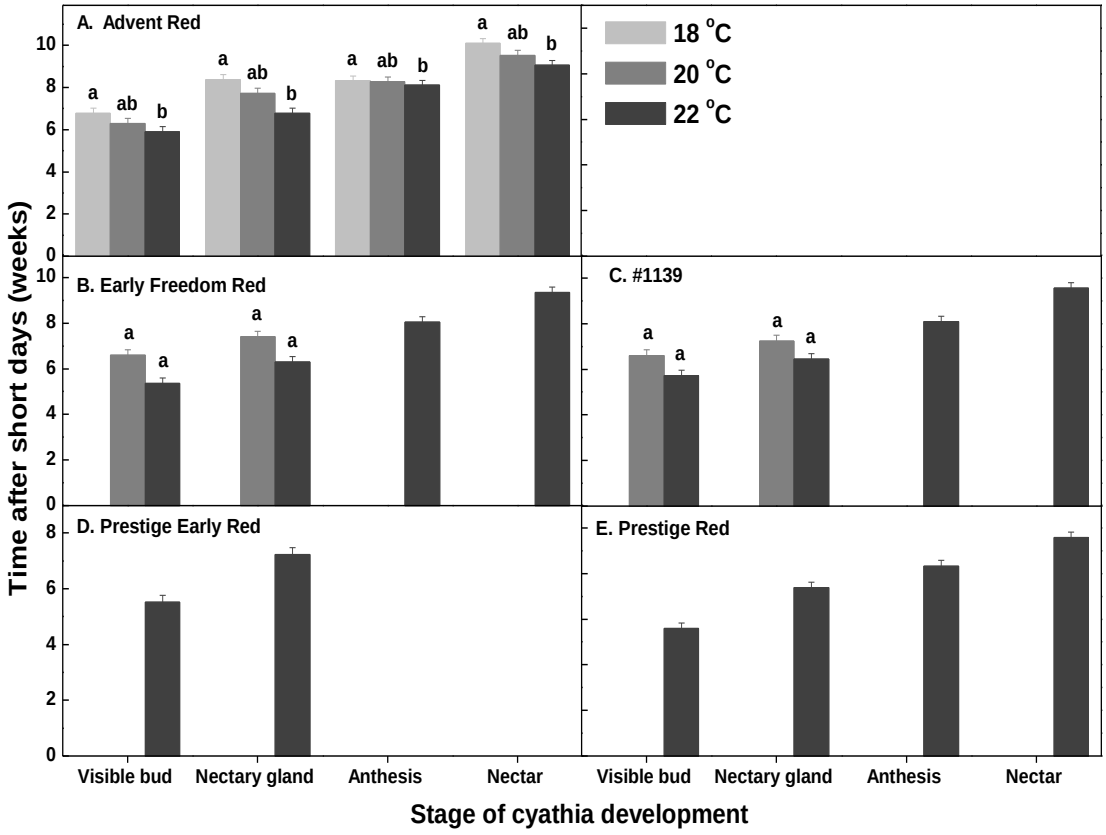

Fig. 3.3. The effect of production temperature on the number of weeks required for the different stages of cyathia development (A) 'Advent Red', (B) 'Early Freedom Red', (C) 'Jubilee Red' (1139), (D) 'Prestige Early Red', (E) 'Prestige Red'. Data were collected when the various stages of cyathia development were observed. No data are presented for plants grown at 15.5°C due to lack of cyathia development. Within-graph and within stage of development means followed by the same letter are not significantly different using Fisher's multiple comparisons procedure (LSD at $p \leq 0.05$).

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CHAPTER FOUR

EFFECT OF PRE-HARVEST TEMPERATURES ON POST-HARVEST LONGEVITY OF FLOWERING POINSETTIAS

Introduction

Poinsettia is a flowering potted plant that is sold for its colorful inflorescences which consist of true flowers, called cyathia, that are subtended by colorful bracts. While the bracts are the most ornamental feature of the inflorescence, the cyathia are indicators of crop maturity and freshness, thus they are essential for successful marketing. Poor cyathia development or premature cyathia abscission can cause a crop to be unmarketable or marketed at a discounted price.

Poinsettias are considered to be ready for market when flowers reach anthesis, which normally occurs in mid to late November. The greenhouse temperatures during the last few weeks of production are typically 18 to 20 °C. Rising fuel costs reduce crop profitability when greenhouses are heated to these temperatures in late October and November. Alternatively, poinsettias could be scheduled for an earlier anthesis date by manipulating photoperiod so that flower development occurs under naturally warmer conditions. Then, the plants could potentially be held in the greenhouse near the base temperature until the market date arrived. The base temperature for poinsettia is near 10 °C (Ecke et al., 2004).

Cyathia retention is a key indicator of poinsettia postharvest longevity. Cyathia abscission is affected by: light, nutrient status, and cultivar selection. Research has shown that low light in the production environment has deleterious effects on the postproduction performance of poinsettia as indicated by leaf and/or cyathia abscission (Miller and Heins, 1986a; 1986b; Nell and Barrett, 1990; Scott et al., 1984a.1984b; Shanks et al., 1970). Low light can be defined as the mean DLI being ≤ 5 mol $m^{-2}d^{-1}$ at plant canopy level in the greenhouse. Pre-harvest factors, such as nutrient status and cultivar selection have been shown to affect plant longevity in potted poinsettia (Scott et al., 1982). High ammonium concentration in the nutrient solution can have a negative influence due to a decrease in pH during cultivation. When pH levels are extremely low, a calcium deficiency may result. Low pH inhibits root growth, thus negatively affecting the size and health of the root system that are important for nutrient movement within the growing plant. Calcium is a critical component of cell walls; therefore, low calcium concentrations during production will result in poor cell wall stabilization and reduced membrane integrity. A poorly developed cyathia due to nutrient (calcium) deficiency will abscise earlier than expected. Calcium is therefore critical during production and that effort should be made to ensure an adequate calcium supply is available for plant uptake. Cultivars differ in their ability to retain cyathia, and 'Gutbier V-10 Amy' was an example of an old cultivar where the cyathia may abscise when the plants are still in the greenhouse (Gordon, 2009). Moe et al. (2006) reported that varieties differ in their cyathia abscission, e.g., 'Millenium' retained cyathia longer than 'Lilo'.

No work has been done on the effect of pre-harvest temperatures on cyathia retention in the postharvest environment; therefore, we conducted experiments with the objective of determining the length of time that five poinsettia cultivars could be held under cold pre-harvest temperatures and still provide an acceptable postharvest performance as defined by cyathia retention.

Materials and Methods

Unrooted cuttings of five poinsettia cultivars ('Advent Red', 'Freedom Early Red', 'Polar Bear', 'Polly's Pink', and 'Prestige Early') were received from Paul Ecke de Guatemala and propagated in Oasis wedges (Smithers-Oasis North America, Kent, Ohio). They were then transplanted into 15-cm diameter plastic pots containing Fafard 3B growing medium (Fafard, Anderson, SC). Incandescent lamps were used for night interruption lighting, which occurred from 10 p.m. to 2 a.m. each night from 16-Sept. to 21-Oct. 2010. Plants were fertilized at each irrigation with water soluble fertilizer 15N-2.2P-12.5K-5Ca-2Mg (Scotts- Sierra Horticultural product Co. Marysville, Ohio) supplying nitrogen at 300 ppm. The experiment was conducted in glass-glazed greenhouse located in Clemson University, South Carolina (34.68 $^{\circ}$N 82.84 $^{\circ}$W) equipped with fan and pad cooling.

One hundred and fifty plants (30 per cultivar) were grown at an average daily temperature of 22.6 °C until the primary cyathium reached anthesis. One primary cyathium is present per shoot and is subtended by three secondary cyathia. After

anthesis, the plants were moved to cold greenhouse to receive pre-harvest temperatures for 1, 2, 3 or 4 weeks. The day temperatures averaged 13 °C and the night temperature averaged 9 °C, while the average daily temperature was 11.0 °C. The average DLI in the pre-harvest environment was 4.2 mol $m^{-2}d^{-1}$. Plants were moved to a postharvest environment, following the pre-harvest temperature treatments. Control plants were moved directly to the postharvest environment without experiencing the pre-harvest environment. The simulated postharvest environment consisted of rooms with fluorescent lights which were turned on from 8 a.m. to 5 p.m. daily. The average light level was 0.5 mol $m^{-2}d^{-1}$ and the average daily temperature was 21°C. The dates of cyathia abscission were recorded for both primary and the secondary cyathia on three stems per plant (5 plants per treatment). The plants were watered in the postharvest environment with tap water. All data were analyzed by analysis of variance and mean separation was accomplished using least significant difference (LSD), $P \leq 0.05$.

Results and Discussion

All cultivars retained their primary cyathium for more than twelve days without a pre-harvest cold treatment. 'Advent Red' and 'Polar Bear' retained their primary cyathium for >14 days while 'Freedom Early Red' and 'Prestige Red' retained their primary cyathia for less than six days following one week of pre-harvest cold treatment (Table 4.1). 'Advent Red' and 'Polar Bear' were the only cultivars that retained their secondary cyathia for more than fourteen days following two to four weeks of pre-harvest cold treatment (Table 4.3). The secondary cyathia on 'Polly's Pink' persisted for 11 days

and ‘Freedom Early Red’ and ‘Prestige Red’ persisted for <6 days following two to four weeks of pre-harvest cold treatment (Table 4.3). If we assume that good postharvest longevity occurs when secondary cyathia are retained for 14 days, then all cultivars met that criterion without a cold pre-harvest temperature treatment; however, only ‘Advent’, ‘Polly’s Pink’ and ‘Polar Bear’ met this criterion following one week of cold pre-harvest temperatures. ‘Advent’ and ‘Polar Bear’ continued to meet this criterion following 4 weeks of cold pre-harvest temperatures.

Our research showed that following 2 to 4 weeks of exposing poinsettias to the cold pre-harvest treatment only two cultivars (‘Polar Bear’ and ‘Advent’) had secondary cyathia that persisted for 14 days in the postharvest environment. In contrast, ‘Prestige Red’, ‘Polly’s Pink’ and ‘Freedom Early Red’ performed relatively poorly in the postharvest environment. This demonstrates that cold pre-harvest treatment performance is cultivar-dependent. In conclusion, cold pre-harvest treatment is a potentially useful commercial technique in cultivars that have strong cyathia development and retention.

Table 4.1. Postharvest longevity (days) of primary cyathia following different durations of the cold pre-harvest temperatures treatment.

Cultivar	Weeks in cold pre-harvest treatment				
	0	1	2	3	4
Advent Red	19 bc	15 d	11 ef	10 fg	11ef
Freedom Early Red	13 de	5 j	5 j	4 j	4 j
Polar Bear	24 a	23 a	20 b	19 bc	17c
Polly's Pink	17 c	11 fg	9 gh	8 gh	8 gh
Prestige Red	12 efgh	6 i	3 j	0 k	0 k

Means depicted with different letters are significantly different using LSD at α=0.05.

Table 4.2. Analysis of variance (ANOVA) table for postharvest longevity (days) of primary cyathia following different duration of cold pre-harvest temperature treatment.

Source	Degrees of freedom	p-value
Cultivar	4	< 0.001
Weeks	4	< 0.001
Cultivar*Weeks	16	0.0126

Table 4.3. Postharvest longevity (days) of secondary cyathia following cold pre-harvest temperatures treatment.

Cultivar	Weeks in cold pre-harvest temperatures				
	0	1	2	3	4
Advent Red	25 b	23 bc	19 ef	18 fg	18 fg
Freedom Early Red	16 fgh	12 i	6 lm	5 mn	6 lm
Polar Bear	29 a	25 b	20 de	19 ef	17 fgh
Polly's Pink	22 cd	16 h	11 ij	9 jk	8 dkl
Prestige Red	16 gh	13 i	7 lm	2 n	2 n

Means within cultivars depicted with different letters are significantly different using LSD at (α=0.05).

Table 4.4. Analysis of variance (ANOVA) table for postharvest longevity (days) of secondary cyathia following different duration of cold pre-harvest temperature treatment.

Source	Degrees of freedom	p-value
Cultivar	4	< 0.001
Weeks	4	< 0.001
Cultivar*Weeks	16	0.0010

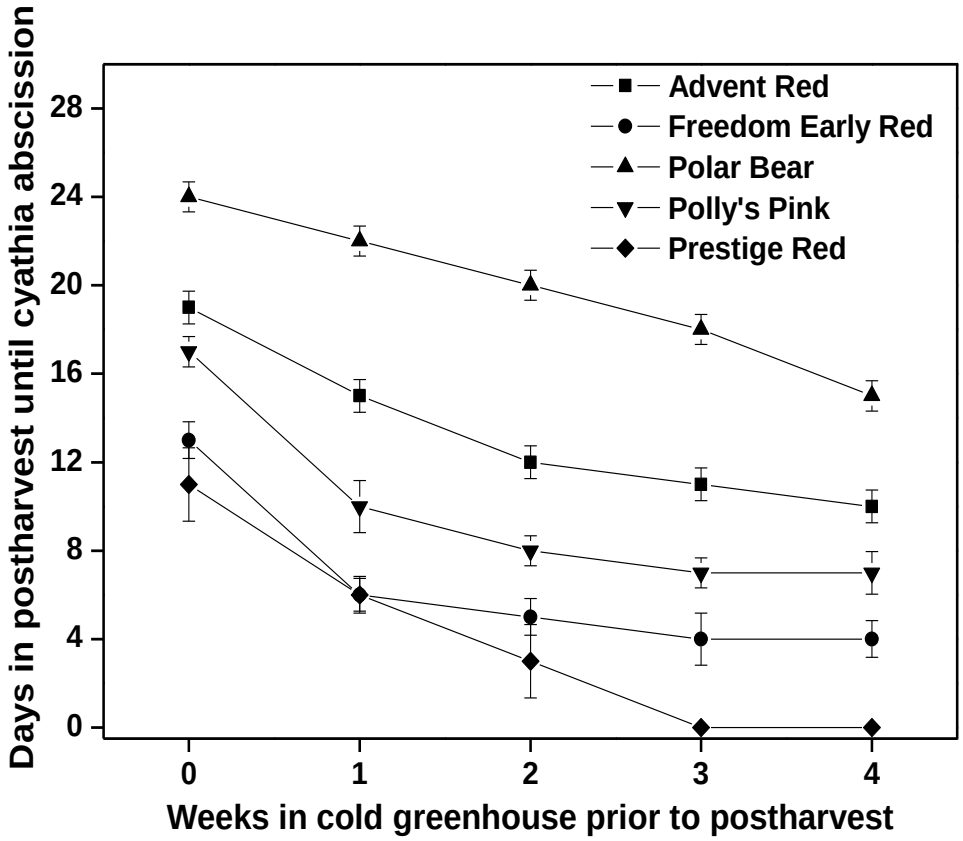

Fig. 4.1. Postharvest longevity (days) of primary cyathia of five poinsettia cultivars following different durations (weeks) of cold (temperature) pre-harvest temperatures treatment. Error bars represent standard error of the mean. Five plants per treatment were used.

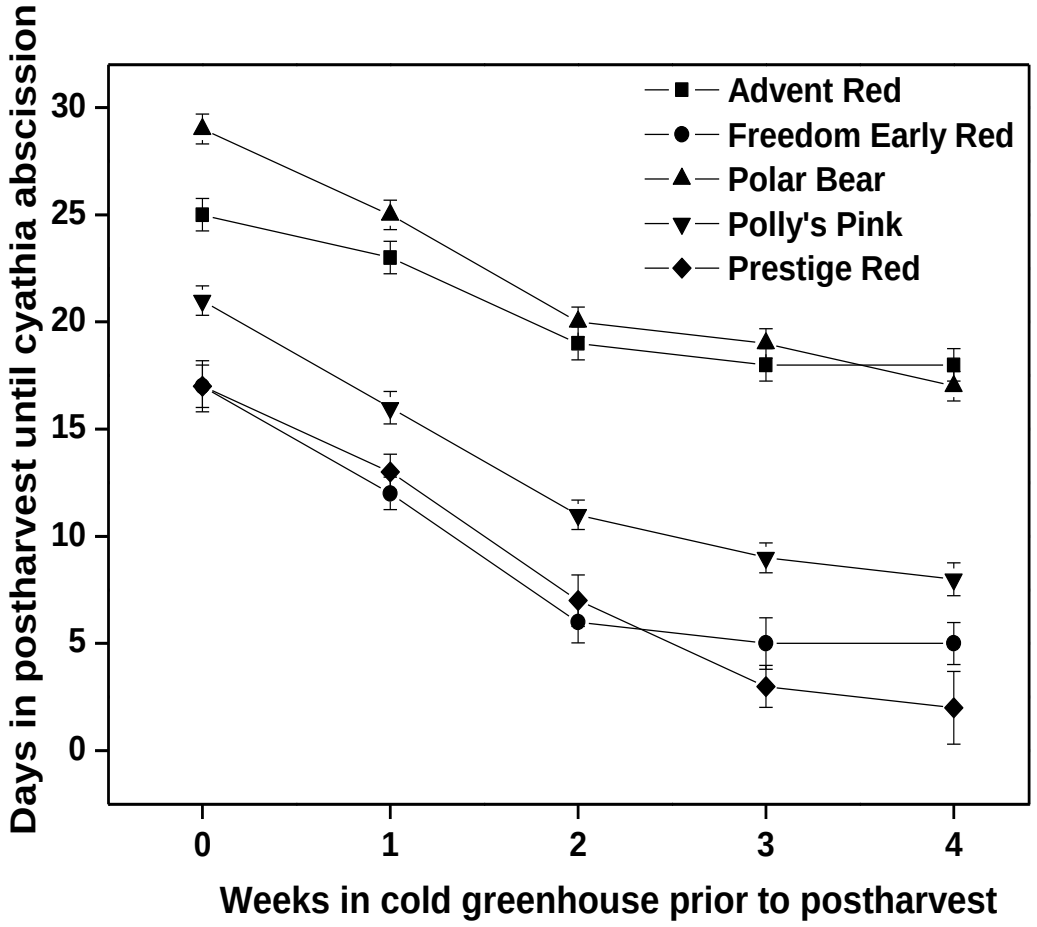

Fig. 4.2. Postharvest longevity (days) of secondary cyathia of five poinsettia cultivars following different durations (weeks) of cold (temperature) pre-harvest temperature treatments. Error bars represent standard error of the mean. Five plants per treatment were used.

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