Regulation of Growth and Branching of Containerized *Penstemon x mexicali* Cultivars

Erika P. Lyons

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Horticulture

Joyce G. Latimer, Chair

Holly L. Scoggins

Erik H. Ervin

May, 1, 2015

Blacksburg, VA

Keywords: PGR, benzyladenine (BA), ethephon, dikegulac sodium, paclobutrazol

Regulation of Growth and Branching of Containerized *Penstemon x mexicali* Cultivars

Erika P. Lyons

ABSTRACT

The primary objectives of this research are to analyze the effects plant growth regulators and pinching practices have on the growth habit of *Penstemon x mexicali* 'Pike's Peak Purple' and 'Red Rocks' and to produce more marketable containerized *Penstemon*. A preliminary study analyzed the effects branching agent PGRs had on 'Pike's Peak Purple.' We found that the PGRs benzyladenine and ethephon were successful at producing more branches than the untreated control when the plants were considered finished in the container. Another group of PGRs known as growth retardants were also evaluated on 'Pike's Peak Purple.' Both high and low rates of foliar applications of paclobutrazol or uniconazole resulted in growth control of the crop. Liner drench or soak applications of paclobutrazol were the most effective at reducing growth but resulted in over-regulated and stunted plants. A separate study focused on the combination of branching agents and pinching practices on 'Pike's Peak Purple.' Both pinching and the application of branching agents improved overall plant quality until the stage of flower initiation where further growth regulation was needed. Based on the results of the previous experiments, we conducted a study combining branching agents and growth retardants on 'Pike's Peak Purple' and 'Red Rocks.' We found that the most marketable 'Pike's Peak Purple' plants were produced with one pinch during the liner stage, two applications of benzyladenine, and one drench application of paclobutrazol. The most marketable 'Red Rocks' plants were produced with one pinch during the liner stage, and two applications of ethephon.

ACKNOWLEDGEMENTS

I would like to express my gratitiude to everyone who supported me in my graduate studies. I would like to thank my advisor Joyce Latimer for her wisdom, guidance, and encouragement. Thank you to Holly Scoggins and Erik Ervin for their advice and guidance. I would like to thank my research technician Margaret Aiken for her knowledge and assistance. Thank you to the undergraduate and graduate students who helped me throughout my research: Mara Grossman, Leslie Peck, James Rockwell, and Elizabeth Harper.

Photo credits: all photos were taken by the author.

Table of Contents

List of Tables

List of Figures

Chapter 1: Literature Review

Introduction

Floriculture is a diverse industry that encompasses a multitude of crops. The U.S. Floricultural industry alone is made up of different categories of plants which include: annual bedding and garden plants, potted flowering plants, indoor/foliage plants, herbaceous perennials, cut flowers, propagative floriculture materials, and cut cultivated greens (USDA, 2014). Herbaceous perennials are an important sector of this floricultural industry and make up 31% of the total bedding and garden category (USDA, 2014). In 2013, the wholesale value of potted herbaceous perennial sales reached $602 million, which was 5 percent higher than in 2012 (USDA, 2014).

Perennials are referred to as plants that live two or more years and typically flower every year once they are fully developed (AHS, 2004b). Herbaceous perennials are often described as non-woody plants that will form stems of flowers every year before setting seed but will then die back in the fall and sprout new growth in the spring (AHS, 2004b). They are a very diverse group of plants with varying growth habits, foliage, and flowers.

Herbaceous perennials often require certain conditions in order to properly grow and flower during container production. These conditions include photoperiod, vernalization, and maintenance practices like pruning and pinching. In most instances, herbaceous perennials are going to require at least one or all of these conditions for them to become marketable, containerized crops. In addition, herbaceous perennials that are vigorous growers may require multiple pinching or pruning applications in order to control growth while in the container. The practice of manually pinching plants is labor-intensive (Starman, 1991) and may not be cost-effective for growers due to labor costs (Latimer and Freeborn, 2009). With increasing demand for herbaceous perennials in gardens and landscapes, growers are faced with challenges in properly growing marketable plants for both the wholesale and retail side of the industry. Application of chemicals known as plant growth regulators may benefit growers by providing an alternative means of controlling the growth of plants and offer the possibility of decreasing the costs associated with labor as a result (Richards and Wilkinson, 1984).

The primary objective of these studies is to analyze the effects plant growth regulators have on the growth habits of the herbaceous perennial *Penstemon* and to determine whether they can be used as an alternative to mechanical methods in producing more marketable and higher quality containerized *Penstemon*.

Penstemon

Penstemon (Schmidel) is one example of an herbaceous perennial grown in the floriculture industry. The *Penstemon* genus is found in the Plantaginaceae family and is native to North America with over 270 species (Broderick et al., 2011). It is found growing naturally in western parts of North America as well as in Central America (Springer, 1999). The *Penstemon* genus contains "plants that are evergreen, deciduous, shrubby, tall, and low-growing" (Neff, 2013). On these plants, the leaves formed may or may not have stalks but are normally lance or linear in shape (AHS, 2004a). Many species in this genus can be found growing in USDA Zones 3 up to 9 (Springer, 1999). When it comes to incorporating these plants into the garden, both large and small species of *Penstemon* can be found growing in different types of gardens and borders (AHS, 2004a). Regardless of placement in the garden, it is important to keep in mind that most *Penstemon* do not tolerate their roots being in damp conditions, so it is best to keep them in soil with good drainage (Neff, 2013).

Penstemon form panicles or racemes that bear tubular-like flowers (AHS, 2004a) that have great color variation with blooms being anywhere from purples to yellows and blues to reds

(Springer, 1999). These flowers normally contain a fifth stamen that is usually infertile and furry and can be seen hanging in its throat (Springer, 1999). This stamen is what gives *Penstemon* the common name beard-tongue (Springer, 1999). Another characteristic of the *Penstemon* flower includes having five, fused petals, which produce two petal lobes on top and three on the bottom (Springer, 1999). These flowers are placed on erect spikes that will attract a range of pollinators (Neff, 2013). *Penstemon* will flower under facultative long day conditions (Neff, 2013).

Two cultivars of *Penstemon* are the main focus of this research and include *Penstemon x mexicali* 'Pike's Peak Purple' and 'Red Rocks.' 'Pike's Peak Purple' and 'Red Rocks' belong to the Mexicali hybrids, which are known to be more compact and more hardy and also found to bear flowers with differing colors and markings on their throats (Springer, 1999). These cultivars are "popular with growers and gardeners because of their floriferous nature, well-branched plant habit and ease of growing over a large range of climates" (Neff, 2013).

Plant Growth Regulators

Plant growth regulators or PGRs are certain types of chemicals that act like hormones and have the ability to affect development and growth habits of plants (Hartmann et al., 2011). Many crops require management or handling by use of mechanical methods such as pinching or shearing to control growth and branching, but with the high labor expenses involved, these methods may not be the most cost effective approaches (Latimer and Freeborn, 2009). PGRs may be an alternative option because of their ability to control growth, decrease apical dominance, and increase lateral buds and branches (Latimer and Freeborn, 2009). In ornamental plant production, PGRs have played key roles in producing more aesthetically appealing crops. For example, foliar applications of different PGRs improved the quality of *Coreopsis rosea* Nutt. 'American Dream' (Burnett et al., 2000). Plant growth regulators improve the quality and marketability of crops in many ways such as improving branching to give plants a fuller appearance in the container, increasing flowering, enhancing foliage color, and promoting more compact growth for easier transport on carts.

Plant growth regulators are applied multiple ways. Application methods include: foliar sprays, sprenches, drenches, liner soaks, and dips (Pilon, 2006). The efficacy of PGRs on plant growth depend not only on measuring the correct volume or rate of the PGR and applying it correctly but also depend on certain environmental factors (Dole and Wilkins, 2005). Environmental factors such as light, relative humidity, air flow, and temperature play key roles in how well a PGR is taken up by the plant (Dole and Wilkins, 2005). These environmental factors are especially crucial for foliar applications of PGRs. Absorption of the PGR is enhanced when air flow is limited, humidity is high, and light levels are low because it is less likely to evaporate as quickly and not be taken up into the plant (Dole and Wilkins, 2005).

Branching Agents

Dikegulac and Dikegulac sodium

Dikegulac and its salt form dikegulac sodium are active ingredients used in plant growth regulators. Its primary function is to turn off points of growth on a plant by acting as a DNA inhibitor (Latimer, 2004). Dikegulac and Dikegulac sodium have primarily been used in the greenhouse industry to enhance branching in crops. Dikegulac sodium increases branching by stimulating development of lateral shoots (Dole and Wilkins, 2005). Foliar applications of dikegulac sodium were found to increase branching in *Rhododendron* L. (Cohen, 1978). In a study focusing on enhancing the aesthetic quality of Boston ferns (*Nephrolepsis exaltata* (L.) Schott 'Compacta'), dikegulac increased the leaf area and shoot count of the Boston fern but did not reduce the length of the fronds as benzyladenine did (Carter et al., 1996). In another study, foliar applications of dikegulac were found to increase lateral branching in the biofuel crop *Jatropha curcas* L. (Abdelgadir et al., 2009). At 2340 or 4680 mg·L^{-1}, dikegulac sodium (Atrimmec, PBI Gordon, Inc. Kansas City, MO) suppressed shoot length and increased shoot number in 'Goldflame' Honeysuckle (*Lonicera x heckrottii 'Goldflame'*) (Bruner et al., 2002). Dikegulac sodium at 4000 or 6000 mg·L^{-1} also provided regrowth that was more uniform on Jack Hedge (*Murraya paniculata* (L.)) and reduced apical dominance in lateral shoots (Kawabata and Criley, 1996). Lateral shoots were increased as a result of application of dikegulac to flame azalea (*Rhododendron calendulaceum* (Michx.) Torr) (Malek et al., 1992).

One plant growth regulator in particular that contains dikegulac sodium is Augeo (OHP, Inc. Mainland, PA). Little Lime™ Hydrangea (*Hydrangea paniculata* 'Jane' (Siebold)) plants treated with 800 or 1600 mg•L^{-1} dikegulac sodium (Augeo) had more branches than hand-pruned plants and plants treated with other PGR treatments (Cochran and Fulcher, 2013). Dikegulac sodium has also shown promise for use on herbaceous perennials. Foliar spray applications of dikegulac sodium increased branching in the herbaceous perennials *Gaillardia aristata* Pursh 'Gallo Yellow', *Echinacea* Moench 'Sombrero Hot Pink,' and *Phlox paniculata* L. 'Laura', primarily at lower spray rates of 400 and 800 mg·L^{-1} (Latimer and Freeborn, 2010). Dikegulac sodium was also found to be effective at increasing branching in herbaceous perennials when applied during the liner stage and again after transplant (Grossman et al., 2013).

Overall, dikegulac sodium is effective as a PGR in increasing branching of greenhouse and nursery crops. However, application of dikegulac sodium, especially at higher concentrations, may cause phytotoxic symptoms such as chlorosis to occur. Chlorosis due to dikegulac sodium application was found in rhododendron (Cohen, 1978), 'Limelight' Hydrangea *(Hydrangea paniculata* Siebold) (Cochran et al., 2013), and in various herbaceous perennials

(Grossman et al., 2013).

Benzyladenine

A class of hormones known as cytokinins are known for their many roles in the formation of shoots, apical dominance, and cell division (Hartmann et al., 2011). Benzyladenine or BA is a synthetic cytokinin (Hartmann et al., 2011). BA has been used on a multitude of greenhouse and nursery crops for the purposes of increasing branching and promoting flowering. In a study on 'Moonbeam' Coreopsis (*Coreopsis verticillata* L.), BA promoted the formation of vegetative and reproductive shoots when applied as a drench or spray to plants at 250 or 500 $mg{\cdot}L^{-1}$ (Farris et al., 2009). These BA applications improved uniformity among plants (Farris et al., 2009). Flowering was promoted in *Doritaenopsis* and *Phalaenopsis* Blume orchids as a result of benzyladenine application (Blanchard and Runkle, 2008). Lateral branching was increased in Apple trees (Malus domestica Borkh) after application of BA (Zamanipour et al., 2012).

Bedding plants like petunia are also affected by BA treatments (Carey et al., 2007). Foliar applications of BA on vegetative petunias (*Petunia x hybrida* Juss.) resulted in more branched plants that were tight and upright (Carey et al., 2007). BA may also be associated with reducing plant height in ornamental crops as well. At 600 $mg{\cdot}L^{-1}$ BA suppressed plant height in Little Lime™ Hydrangea but did not, however, influence plant branching (Cochran and Fulcher, 2013).

One plant growth regulator product known as Configure (Fine Americas, Inc. Walnut Creek, CA), which contains BA, is effective in herbaceous perennial production. In a study by Latimer and Freeborn (2009), 600 $mg{\cdot}L^{-1}$ BA applied as a foliar spray increased branching in certain herbaceous perennials. For instance, *Penstemon* 'Husker Red' had increased basal branching four weeks after the BA treatment was applied when compared to the control and also had reduced plant height as well (Latimer and Freeborn, 2009). BA can also be applied to certain herbaceous perennials during the liner stage to produce a fuller liner with more branching (Grossman et al., 2012). However, several applications could possibly prove favorable, e.g., before transplanting or soon after transplanting, to improve the finished plant product (Grossman et al., 2012).

In addition to enhancing branching, flowering, and compaction, BA may also reduce root growth but in such a way that it would not have a significant effect on the quality of the finished, containerized plant. In the liner study mentioned previously, some of the liners treated with BA expressed reduced root growth that did not impact the final plant products (Grossman et al., 2012).

Ethephon

Ethephon is a PGR that breaks down into ethylene once it enters and is absorbed by plant tissue (Hartmann et al., 2011). It is used to reduce apical dominance in crops, as well as to control flowering and ripening (Hartmann et al., 2011). Ethephon has also been used as a plant growth retardant for reducing plant height and width in certain floriculture crops. Foliar concentrations for ethephon-containing products such as Florel are recommended at 250-500 $mg \cdot L^{-1}$ for application on plants (Styer, 2002). Foliar spray applications of ethephon at 500 $mg \cdot L^{-1}$ reduced height in zonal geranium (*Pelargonium hortorum* (L.H.Bailey)) growth (Tayama and Carver, 1990). In a study on the effects of ethephon on flowering and growth, ethephon delayed flowering and reduced height in several herbaceous perennials (Hayashi et al., 2001). In regards to vegetative annuals, ethephon was effective in reducing height and/or width index for 22 out of the 27 cultivars studied (Starman et al., 2004). Ethephon at 500 or 1000 $mg \cdot L^{-1}$ suppressed the height of Little Lime™ Hydrangea (Cochran and Fulcher, 2013), and promoted more compact plants and decreased growth indices at 500 and 1000 $mg \cdot L^{-1}$ in torch blanketflower (*Gaillardia pulchella* Foug.) (Hammond et al., 2007).

Ethephon may also be used for the purpose of increasing branching by promoting axillary shoot development (Dole and Wilkins, 2005). In a study regarding the effects of PGRs on Jerusalem Cherry (*Solanum pseudocapsicum* L.), ethephon was effective at increasing first order lateral branching, especially at 450 $mg \cdot L^{-1}$ (Khosh-Khui et al., 1979). In a study on Kalanchoe (*Kalanchoe* Adans.) species, foliar sprays of ethephon or benzyladenine increased branching in a number of species (Currey and Erwin, 2012). Another study focusing on stock plant management of *Coreopsis verticillata* 'Moonbeam' and *Veronica longifolia* L. 'Sunny Border Blue' plants found that ethephon applied biweekly at 600 $mg \cdot L^{-1}$ or applied weekly at 400 $mg \cdot L^{-1}$ resulted in more branches and cuttings (Glady et al., 2007).

Although ethephon has commonly been applied as a foliar spray, research is currently being done to determine whether it would also be effective when applied as a substrate drench. Miller et al. (2012) performed several experiments regarding the effect an ethephon drench has on various floriculture crops that included 24 bedding plant cultivars and 12 *Narcissus* L. cultivars. They found that the ethephon drenches resulted in reduced stem elongation and biomass accumulation as well as delayed flowering in these floriculture crops and concluded the potential for this method of application for the purposes of height control and growth reduction (Miller et al., 2012).

Growth Retardants

In the greenhouse industry, there are plant growth regulators available that inhibit gibberellin biosynthesis (Hartmann et al., 2011). Gibberellins are primarily known for their function in cell elongation and division but also serve other functions in plant development

(Mutasa-Göttgens and Hedden, 2009). By preventing the production of gibberellins, plant growth is reduced as a result (Pilon, 2006). These plant growth regulators, also known as plant growth retardants are important tools in controlling growth of floriculture crops (Dole and Wilkins, 2005). Common growth retardants used in the industry include paclobutrazol, chlormequat chloride, ancymidol, uniconazole, daminozide, and flurprimidol. Other than growth control, several of these PGRs are responsible for producing deeper green foliage as well. In a study of Dutch-grown bleeding heart (*Dicentra spectabilis* (L.) Lem.), deep green leaf color was seen on plants that received drenches and/or sprays of daminozide, paclobutrazol, ancymidol, and uniconazole (Kim et al., 1999). Darker green foliage was evident on *Dianthus* (*Dianthus caryophyllus* L., *Dianthus chinensis* L.) after application of paclobutrazol (Foley and Keever, 1991). Plant growth retardants can be applied to plants numerous ways including foliar applications that are taken up through the leaves or root ball soaks or substrate drench applications that are taken up via the roots from media saturated with PGR solution. The method of application depends on the specific PGR used. Plant growth retardants like daminozide are only taken up through the leaves and so must be applied as a foliar spray, whereas paclobutrazol and uniconazole can additionally be taken up through the roots or stems and so can also be applied as a substrate drench or soak (Latimer, 2004).

Foliar applications are effective in growth control in floriculture crops. In a study on Kalanchoe species, all of the kalanchoe species studied had suppressed stem elongation resulting from foliar applications of uniconazole and paclobutrazol, but foliar applications of chlormequat chloride and daminozide were not as effective (Currey and Erwin, 2012). Whipker and Dasoju (1998) studied how foliar applications of daminozide, uniconazole, and paclobutrazol affected growth in potted sunflowers (*Helianthus annuus* L. 'Pacino'). They found that uniconazole concentrations of 16 to 32 mg·L^{-1} and daminozide concentrations of 4,000 to 8,000 mg·L^{-1} were effective treatments for producing shorter and more marketable potted sunflowers (Whipker and Dasoju, 1998). Hilgers et al. (2005) found foliar applications of paclobutazol and chloromequat chloride were effective at controlling height in seashore mallow (*Kosteletzkya virginica*).

Drenches are another type of growth retardant application used effectively in the greenhouse industry. Drenches involve applying a certain amount of PGR solution evenly over the media of crops in their final containers (Pilon, 2006). The benefit of drenching is that the PGR solution is taken up by the plant over time and continually regulates growth as the roots fill out the pot and take up the PGR. Uniconazole drenches used on torch blanketflower resulted in more compact plants with decreased growth indices of 12% to 30%. (Hammond et al., 2007). In another study, drenches of paclobutrazol or uniconazole applied to pampas grass [*Cortaderia selloana* (Schult. & Schult. f.) Asch. & Graebn.] resulted in shorter plant heights (Sellmer et al., 2001). Uniconazole and paclobutrazol were applied as substrate drench applications to ornamental cabbage and kale (*Brassica oleracea* var. acephala), which resulted in shorter and more compact plants (Gibson and Whipker, 2001). In some instances, drench applications can be more effective at growth regulation than foliar applications. In one study, substrate drench applications of paclobutrazol and uniconazole were more effective at producing compact Osteospermum (*Osteospermum ecklonis* (DC.) Norl.) cultivars than foliar spray applications (Gibson and Whipker, 2003). Although drench applications are effective at reducing plant growth, it is important to test different concentrations in order to find the optimum concentration for plant quality and marketability and to figure out at what point concentrations are too high and can actually become detrimental to plant quality. For instance, in a study examining potted sunflowers, paclobutrazol drenches at 2 and 4 mg were effective at producing shorter, marketable sunflowers, whereas at 16 mg and 32 mg, severe height retardation and phytotoxicity occurred (Dasoju et al., 1998).

Finally, growth retardants can be applied in the liner stage before transplanting into the final container as a liner soak (Pilon, 2006). Liner soaks can also be applied like a drench, in which the PGR solution is applied over the media and then taken up by the root ball. Another way liner soaks are applied are as dip applications which involve dipping the root ball of a vegetative liner or plug into a PGR solution, where the PGR is also taken up by the roots (Latimer, 2004). Blanchard and Runkle (2007) found that liner dip applications of paclobutrazol or uniconazole produced shorter stems in several bedding plants.

Literature Cited

Abdelgadir, H.A., S.D. Johnson, and J. Van Staden. 2009. Promoting branching of a potential biofuel crop *Jatropha curcas* L. by foliar application of plant growth regulators. Plant Growth Regul. 58:287-295.

Blanchard, M.G. and E.S. Runkle. 2007. Dipping bedding plant liners in paclobutrazol or uniconazole inhibits subsequent stem extension. HortTechnology 17(2): 178-182.

Blanchard, M.G. and E.S. Runkle. 2008. Benzyladenine promotes flowering in *Doritaenopsis* and *Phalaenopsis* orchids. J. Plant Growth Regul. 27: 141-150.

Broderick, S.R., M.R. Stevens, B. Geary, S.L. Love, E.N. Jellen, R.B. Dockter, S.L. Daley, and D.T. Lindgren. 2011. A survey of Penstemon's genome size. Genome 54(2): 160-173.

Bruner, L.L., G.J. Keever, J.R. Kessler, Jr., and C.H. Gilliam. 2002. Atrimmec suppresses shoot length and promotes branching of *Lonicera x heckrottii* 'Goldflame' (Goldflame Honeysuckle). J. Environ. Hort. 20(2):73-76.

Burnett, S.E., G.J. Keever, J.R. Kessler, and C.H. Gilliam. 2000. Foliar applications of plant growth retardants to *Coreopsis rosea* ‘American Dream.’ J. Environ. Hort. 18(2): 59-62.

Carey, D., B. Whipker, I. McCall, and W. Buhler. 2007. Cytokinin based PGR affects growth of vegetative petunia. SNA Research Conference. 52:101-109.

Carter, J., B.P. Singh, and W. Whitehead. 1996. Dikegulac, but not benzyladenine enhances the aesthetic quality of Boston fern. HortScience 31(6):978-980.

Cochran, D.R. and A. Fulcher. 2013. Type and rate of plant growth regulator influence vegetative, floral growth, and quality of Little Lime Hydrangea. HortTechnology 23(3):306-311.

Cochran, D.R., A. Fulcher, and G. Bi. 2013. Efficacy of dikegulac sodium applied to pruned and unpruned ‘Limelight’ Hydrangea grown at two locations in the southeastern United States. HortTechnology 23(6): 836-842.

Cohen, M.A. 1978. Influence of dikegulac sodium, off-shoot-o and manual pinching on rhododendrons. Scientia Horticulturae 8: 163-167.

Currey, C.J. and J.E. Erwin. 2012. Foliar applications of plant growth regulators affect stem elongation and branching of 11 Kalanchoe species. HortTechnology 22(3):338-344.

Dasoju, S., M.R. Evans, and B.E. Whipker. 1998. Paclobutrazol drenches control growth of potted sunflowers. HortTechnology 8(2):235-237.

Dole, J. M., and H. F. Wilkins. 2005. Plant growth regulation, p.141-161. In: Floriculture: principles and species. 2nd ed. Prentice Hall, Upper Saddle River, N.J.

Farris, M.E., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of 'Moonbeam' Coreopsis. J. Environ. Hort. 27(3):176-182.

Foley, J.T. and G.J. Keever. 1991. Growth regulators and pruning alter growth and axillary shoot development of *Dianthus*. J. Environ. Hort. 9(4): 191-195.

Gibson, J.L. and B.E. Whipker. 2001. Ornamental cabbage and kale growth responses to daminozide, paclobutrazol, and uniconazole. HortTechnology 11(2):226-230.

Gibson, J.L. and B.E. Whipker. 2003. Efficacy of plant growth regulators on the growth of vigorous Osteospermum cultivars. HortTechnology 13(1):132-135.

Glady, J.E., N.S. Lang, and E.S. Runkle. 2007. Effects of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. HortScience 42(7):1616-1621.

Grossman, M., J. Freeborn, H. Scoggins, and J. Latimer. 2012. Benzyladenine increases branching but reduces root growth of herbaceous perennial liners. HortScience 47(8):1085-1090.

Grossman, M., J. Freeborn, H. Scoggins, and J. Latimer. 2013. Timing of benzyladenine and dikegulac sodium application affects branching of liners and finished herbaceous perennial plants. HortScience 48(7):875-882.

Hammond, H.E., R.K. Schoellhorn, S.B. Wilson, and J.G. Norcini. 2007. Differing blanketflower cultivar and ecotype responses to plant growth regulators. HortTechnology 17(4):552-556.

Hartmann, H.T., D.E. Kester, F.T. Davies, Jr., and R. L. Geneve. 2011. Biology of plant propagation, p.14-48. In: Plant propagation principles and practices. 8th ed. Prentice Hall, Upper Saddle River, N.J.

Hayashi, T., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Ethephon influences flowering, height, and branching of several herbaceous perennials. *Scientia Horticulture* 91:305-323.

Hilgers, K.R., C. Haynes, and W.R. Graves. 2005. Chemical height of containerized seashore mallow. HortTechnology 15(2): 330-332.

Kawabata, O. and R.A. Criley. 1996. Dikegulac sodium spray enhances uniform regrowth of *Murraya paniculata* (L.) Jack Hedge. HortScience 31(2):244-246.

Khosh-Khui, M., Rouhani, I., and Shaybany, B. 1979. Response of Jerusalem cherry to growth regulators. Can. J. Plant Sci. 59: 75-79.

Kim, S.H., A.A. De Hertogh, and P.V. Nelson. 1999. Effects of plant growth regulators applied as sprays or media drenches on forcing of Dutch-grown bleeding heart as a flowering potted plant.

HortTechnology 9(4):630-635.

Latmer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Ann. Conf. Plant Growth Regulator Society Amer. 31:1-4.

Latimer, J. and J. Freeborn. 2009. New Uses of PGRs in ornamentals: Configure (6-BA) increases branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 36:88-93.

Latimer, J. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Malek, A.A., F.A. Blazich, S.L. Warren, and J.E. Shelton. 1992. Growth response of seedlings of flame azalea to manual and chemical pinching. J. Environ. Hort. 10(1): 28-31.

Miller, W.B., N.S. Mattson, X. Xie, D. Xu, C.J. Currey, K.L. Clemens, R.G. Lopez, M. Olrich, and E.S. Runkle. 2012. Ethephon substrate drenches inhibit stem extension of floriculture crops. HortScience 47(9):1312-1319.

Mutasa-Göttgens, E. and P. Hedden. 2009. Gibberellin as a factor in floral regulatory networks. Journal of Experimental Botany 60(7): 1979-1989.

Neff, M. 2013. How to grow and sell Penstemon. Greenhouse Grower 13 January 2014. <http://www.greenhousegrower.com/uncategorized/how-to-grow-and-sell-penstemon/>.

The American Horticultural Society (AHS) A-Z encyclopedia of garden plants. 2004a. Penstemon, p.766-769. Revised American Edition. DK Publishing, New York, NY.

The American Horticultural Society (AHS) A-Z encyclopedia of garden plants. 2004b. Perennials, p.38-39. Revised American Edition. DK Publishing, New York, NY.

Pilon, P. 2006. Controlling plant height of perennial crops, p.201-248. In: Perennial solutions: a grower's guide to perennial production. Ball, Batavia, IL.

Richards D. and Wilkinson, R.I., 1984. Effect of manual pinching, potting-on and cytokinins on branching and flowering of *Camellia, Rhododendron* and *Rosa*. Sci. Hortic., 23: 75-83.

Sellmer, J.C., C.R. Adkins, I. McCall, and B.E. Whipker. 2001. Pampas grass responses to ancymidol, paclobutrazol, and uniconazole substrate drenches. HortTechnology 11(2):216-219.

Springer, L. 1999. Penstemons: The all-american perennial. Horticulture 96(5):42-46.

Starman, T.W. 1991. Response of Kientzler New Guinea impatiens to manual and chemical pinching. HortScience 26(7): 856-857.

Starman, T.W., M.C. Robinson, and K.L. Eixmann. 2004. Efficacy of ethephon on vegetative annuals. HortTechnology 14(1): 83-87.

Styer, R.C. 2002. Using Florel effectively. Greenhouse Production News 12(10): 10-15.

Tayama, H.K. and S.A. Carver. 1990. Zonal geranium growth and flowering responses to six growth regulators. HortScience 25(1): 82-83.

USDA 2014. Floriculture Crops 2013 summary. June 2014. <http://www.nass.usda.gov/Statistics_by_State/New_Jersey/Publications/Floriculture_Statistics/FlorCrop-06-19-2014.pdf/>.

Whipker, B.E. and S. Dasoju. 1998. Potted sunflower growth and flowering responses to foliar applications of daminozide, paclobutrazol, and uniconazole. HortTechnology 8(1):86-88.

Zamanipour, M., E.Ganji Moghadam, and A. Asgharzade. 2012. The effects of heading and benzyladenine applications on branching of apple (cvs. ‘Red Delicious’ and ‘Golden Delicious’) trees in nursery. African J. Agricultural Research 7(30): 4297-4304.

Chapter 2: Evaluation of PGR Branching Agents and Pinching on *Penstemon x mexicali* 'Pike's Peak Purple'

Introduction

The greenhouse and nursery industries are faced with several challenges when growing containerized crops. One of these challenges involves growing compact, well branched plants that will not overgrow the container while in production. Several ways that growers try to regulate growth is by manual processes such as pruning and pinching. Pinching promotes branching by enhancing lateral bud growth as a result of breaking apical dominance by the removal of apical shoots and buds (Starman, 1991). However, these methods can be labor-intensive and not cost-effective for very vigorous crops because of how often they need to be pinched in order to continue regulating growth and prevent apical dominance from recurring (Richards and Wilkinson, 1984). Alternative methods are being explored to grow and sell marketable containerized plants without the additional costs and labor involved with these traditional methods. Plant growth regulators or PGRs are a possible option for growers. Plant growth regulators can vary in function from reducing the overall growth of a plant to enhancing branching and flowering that can improve quality overall. Certain PGRs known as branching agents are able to promote basal and/or lateral branching in plants, which could aid in improving the quality of the crop while it is being grown in the container. Three PGR agents that are utilized most in the floriculture industry to influence branching are ethephon, benzyladenine, and dikegulac (Starman et al., 2004).

These PGRs known for enhancing branching act as chemical pinchers by preventing the development of apical shoots and promoting the development of lateral buds that will eventually develop into new branches (Latimer and Freeborn, 2009). Dikegulac and its salt form dikegulac sodium have been used to promote branching in crops by acting as a chemical pinching agent (Grossman et al., 2013). In one study, different foliar spray applications of dikegulac sodium were applied to the herbaceous perennials *Echinacea* Moench 'Sombrero Hot Pink,' *Gaillardia aristata* Pursh 'Gallo Yellow', and *Phlox paniculata* L. 'Laura' and increased branching depending on the rate used (Latimer and Freeborn, 2010). Another branching agent that has been used in the floriculture industry is benzyladenine, a synthetic cytokinin that promotes branching in certain crops. Several herbaceous perennial liners had increased branching as a result of receiving different foliar applications of benzyladenine (Grossman et al., 2012). Ethephon is another PGR used in the industry that is able to promote branching as well as reduce stem elongation and inhibit flowering through the release of ethylene gas as it is absorbed into plant cells (Glady et al., 2007). In one particular study, foliar applications of ethephon increased lateral branching in the ornamental crop Jerusalem cherry (*Solanum pseudocapsicum* L.) (Khosh-Khui et al., 1979).

The floriculture crop that is the focus of this research is *Penstemon* Schmidel. The *Penstemon* genus is a group consisting primarily of herbaceous or woody perennials that are found as wildflowers in North America (Lindgren and Wilde, 2003a). *Penstemon* are known for their tubular flowers that are split into five lobes and come in a range of colors (Horn, 2005). Their common name "Beardtongue" comes from the sterile staminode that is found in the flower tube (Lindgren and Wilde, 2003b). The growth habit of *Penstemon* varies anywhere from more upright, shrub-like species to shorter, basal rosette species (Neff, 2013). *Penstemon* may require certain conditions in order to grow properly in the floriculture industry. For instance, some species may require vernalization in order to flower properly, and the taller, more vigorous species could benefit from application of PGRs (Neff, 2013).

The objectives of these studies are to analyze the effects of pinching and certain PGRs on branching and growth regulation of different *Penstemon* species and to determine which practices are the most beneficial at improving the overall quality and marketability of containerized *Penstemon*.

Materials and Methods

Evaluating Branching Agent Applications on *Penstemon x mexicali* 'Pike's Peak Purple'

Unrooted cuttings of *Penstemon x mexicali* 'Pike's Peak Purple' were obtained from Aris Horticulture Inc. (Barberton, Ohio). The cuttings were stuck in 72 size flats (height 5.71 cm, volume 35.4 ml) filled with a peat-based soilless substrate (Fafard 1P, Sun Gro Horticulture Canada Ltd., Agawam, MA) on December 4, 2013. The lower 2 cm of the cuttings were dipped in 1000 $mg \cdot L^{-1}$ IBA rooting hormone solution (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) for 3 seconds prior to sticking. The cuttings were allowed to root under mist in a glass greenhouse for 2 or 3 weeks. While under mist, the cuttings were irrigated without fertilizer. After the cuttings were rooted, they received 13N-0.9P-10.8K (Peter's Plug and Bedding Plant Special, The Scotts Co. LLC, Marysville, OH) at 100 $mg \cdot L^{-1}$ N via constant liquid feed (CLF). The liners were then transplanted into trade gallon-sized pots (2.8 L) containing a peat-based soilless media (Fafard 3B, Sun Gro Horticulture Canada Ltd.) and received 150 $mg \cdot L^{-1}$ N of 15N-2.2P-12.5K-4Ca-2Mg (Jack's Professional, J.R. Peters Inc., Allentown, PA) via CLF for the remainder of their production. After transplant, the potted plants were grown and finished in a greenhouse with a double layer covering of polyethylene. The temperature of the greenhouse averaged 19.6°C with a daily light integral (DLI) of 10.3 $mol \cdot m^{-2} \cdot d^{-1}$ during the growing period for 'Pike's Peak Purple.' In addition to natural lighting, HPS supplemental lights were set for 16 hour, long days.

The branching agents were applied twice as foliar sprays at a volume of 210 $ml \cdot m^2$, once during liner production (Figure 2.1) and again after transplant. The first treatment was applied

26 days after cuttings were stuck, when the plants formed roots that were evident on all four sides of their root ball but were not yet ready to transplant. The second spray was then applied two weeks after the first, about one week after the plants were transplanted. These branching agents were compared to an untreated control: 400 $mg \cdot L^{-1}$ dikegulac sodium (Augeo, 18.5%; OHP, Inc., Mainland, PA), 600 $mg \cdot L^{-1}$ benzyladenine (Configure, 2%; Fine Americas, Inc., Walnut Creek, CA), or 500 $mg \cdot L^{-1}$ ethephon (Collate, 21.7%; Fine Americas, Inc.). Rates for the branching agents were based on preliminary studies. Plants were arranged in a completely randomized design with six cellpak unit replications (two plants per unit) per PGR for the liner stage and eight single plant replications per PGR for plants selected for the grow out phase.

Data were collected 0, 2, 4, 6, and 9 weeks after the initial PGR applications (WAIT) for 'Pike's Peak Purple.' Plants were measured for plant height (from rim of the pot to the top of the plant), plant width (average of the largest width and the width perpendicular to the largest width), number of leaders (primary branches with secondary lateral branches), number of branches, and flower stalk height (9 WAIT). Flower stalk height was measured from the rim of the pot to the top of the flower stalk. Days to open flower were noted. Phytotoxicity was also evaluated and rated on the following scale (Figure 2.2):

0) No damage or injury

1) Slight injury (less than 1/3 of plant affected)

2) Mild injury (1/3 of the plant affected)

3) Moderate injury (1/3 to 1/2 of plant affected)

4) Severe injury (more than 1/2 of plant affected)

5) Permanent injury and damage (entire plant is affected)

Shoot dry weights were measured at the time of the first foliar application (Day 0 plants) and then again at the final data collection (9 WAIT). Data were analyzed using Analysis of Variance ($P \leq 0.05$, Student's *t* test) through JMP Pro 10.

Evaluating Branching Agents and Pinching on *Penstemon* 'Pike's Peak Purple'

Unrooted cuttings of 'Pike's Peak Purple' were obtained from Aris Horticulture Inc. on June 27, 2014 and stuck in 72 size flats as described for the previous experiment. The cuttings were allowed to root under mist in a glass greenhouse for 2 weeks and were irrigated without fertilizer. After the cuttings were rooted, they received 150 $mg \cdot L^{-1}$ N of 15N-2.2P-12.5K-4Ca-2Mg (Jack's Professional, J.R. Peters Inc.). The liners were then planted and grown as described above in the previous experiment. The temperature of the greenhouse averaged at 19.7°C with a DLI of 20.1 $mol \cdot m^{-2} \cdot d^{-1}$ during the growing period. In addition to natural lighting, HPS supplemental lights were set for 16 hour, long days.

The experiment was set up as a split plot design with pinching as the main plot factor and branching agents as the subplot factor. An unpinched, untreated control was maintained as a visual comparison. Plants were pinched once (at the liner stage to remove all but 5 nodes, Figure 2.3A) or twice (at the liner stage and again 24 days after transplanting to remove only the terminal bud, Figure 2.3B). Branching agents were applied as foliar sprays and included an unsprayed control, 600 $mg \cdot L^{-1}$ dikegulac sodium, 600 $mg \cdot L^{-1}$ benzyladenine, or 500 $mg \cdot L^{-1}$ ethephon. The rates of benzyladenine and ethephon remained the same from the previous experiment, but the dikegulac sodium rate was increased based on the results of the first study. The branching agents were applied once as a foliar spray at a volume of 210 $ml \cdot m^2$ during liner production 10 days after the first pinch had occurred, and the plants had been given time to regrow more leaf area. There were eight single plant replications per treatment group. Data were analyzed using a split-plot design and analysis of variance ($P \leq 0.05$, Student's *t* test) through JMP Pro 10.

Data were collected 0, 2, 4, 6, and 9 weeks after PGR application (WAT) for 'Pike's Peak

Purple'. Plants were measured as described for the previous experiments. Phytotoxicity was also evaluated and rated as necessary as defined in the previous experiment (Figure 2.4). Marketability was evaluated at the final data collection and rated plants on the following scale:

0) Death, not salable

1) Unacceptable/extremely poor quality, unsalable

2) Poor quality, unsalable

3) Okay/fair quality, some salability

4) Good quality, salable

5) Excellent/ideal quality, salable

Results (See Appendix for complete data tables)

Evaluating Branching Agent Applications on *Penstemon x mexicali* 'Pike's Peak Purple'

Plant measurements taken at the time of the first initial application (0 WAIT) of the branching agents indicated sufficient uniformity between the groups (data not presented, Figure 2.1). No significant differences were seen in plant height, average width, or number of leaders at 2 weeks after the initial PGR application (data not presented, Figure 2.5). Plants sprayed with benzyladenine had an early increase in branching compared to the other treatment groups at 2 WAIT (data not presented). Phytotoxicity was seen in both the ethephon and benzyladenine groups at 1 and 2 WAIT (data not presented). Symptoms of phytotoxicity included twisting of leaves in the ethephon group and red/purple discoloration of leaves in the benzyladenine group (Figure 2.2). These symptoms were minor and did not significantly reduce the overall quality and salability of the plants.

At 4 WAIT, height was reduced by both the benzyladenine (10%) and ethephon (28%) applications compared to the control group (Table 2.1, Figure 2.5). Ethephon reduced average width 21% as compared to the control group. The number of leaders was not significantly different between the branching agents at 4 or 6 WAIT (data not presented). An increased number of branches was seen with the ethephon or dikegulac sodium applications at 4 WAIT. Phytotoxicity persisted in plants subjected to a second application of benzyladenine or ethephon with the same symptoms as described above at 2 WAIT (Table 2.1).

By 6 WAIT, plant height and average width were reduced by 27% in the ethephon group compared to the control (Table 2.1, Figure 2.6). Ethephon also significantly increased the number of branches compared to the control and other PGR groups.

At the final data collection (9 WAIT), plant height was not significantly affected by any of the PGR applications (Table 2.2, Figure 2.6). However, ethephon reduced flower stalk height 23% compared to the control. Average width was reduced 14% by both ethephon and dikegulac sodium applications as compared to the control. There was no significant difference in the number of leaders until the final data collection where ethephon had the fewest leaders. Benzyladenine and ethephon significantly increased the number of branches compared to the control and dikegulac sodium groups. Ethephon delayed flowering about 7 days. Plants sprayed with benzyladenine had 6x more flower stalks than plants in the other groups (Figure 2.6). Flowering was evaluated at the final data collection, and the ethephon group took longer to flower by 8 days and had fewer plants flowering as compared to the control group. Only ethephon reduced shoot dry weight as compared to the control.

Evaluating Branching Agents and Pinching on *Penstemon* 'Pike's Peak Purple'

Plant evaluation at 2 weeks after the application (WAT) of PGRs describes only the effect of PGRs on plants pinched once (Figure 2.7). The second pinch was conducted 1 day after the plant evaluation and 24 days after the first pinch. Plant height was reduced 29% by benzyladenine and 44% by ethephon (Table 2.3). Average width was reduced by all three PGRs compared to controls. Benzyladenine reduced average width 32%, ethephon 35%, and dikegulac sodium 19%. Dikegulac sodium caused an early increase in the numbers of leaders and branches compared to the other groups. Mild phytotoxicity was seen in all groups that received a PGR application, but plants receiving benzyladenine were the most affected. Symptoms of phytotoxicity varied between the PGRs (as seen at 1 WAT, Figure 2.4). Benzyladenine caused red/purple discoloration on the leaves. Ethephon caused mild leaf twisting, and dikegulac sodium caused some leaf chlorosis. The discoloration, twisting, and chlorosis mildly impacted the quality of the plants, but the plants grew out of the phytotoxicity before the 4 WAT assessment.

At 4 weeks after the PGR application which was 2 weeks after the second pinch, height was reduced by 37% in the plants that were pinched twice compared to those pinched once (Table 2.4, Figure 2.8). There was no significant interaction between the number of pinches and branching agents applied in any of the variables measured at 4 WAT. Benzyladenine reduced plant height 23%, and ethephon reduced plant height 32% compared to the control. Average width was reduced 32% in plants pinched twice compared to those pinched once. Benzyladenine reduced average width 22%, ethephon 32%, and dikegulac sodium 15%. Plants pinched twice had more leaders than those pinched once. The number of branches was not significantly different between plants pinched once or twice. Plants treated with branching agents, especially benzyladenine, had fewer leaders and branches than the control plants.

At 6 weeks after the foliar PGR application, height was reduced 19% in plants pinched twice compared to those pinched once (Table 2.4, Figure 2.9). There also was an interaction between the number of pinches and branching agents applied for height. In the plants pinched once, benzyladenine reduced height 27%, ethephon 16%, and dikegulac sodium 27% compared to the controls. However, although height of plants pinched twice was also reduced by PGR applications, ethephon caused the greatest percent reduction at 27% compared to controls. Ethephon was more effective at reducing height in the plants pinched twice than in the plants pinched once. Average width was reduced 21% in plants pinched twice compared to those pinched once. There was no interaction between pinching and the PGRs for average width. In the subplot, benzyladenine reduced average width 11%, ethephon 17%, and dikegulac sodium 9%. There was no significant difference in the number of leaders between the once and twice pinched plants and no significant interaction between number of pinches and branching agents. All PGRs reduced the number of leaders. A greater number of branches was found in the plants pinched once than those pinched twice. There was a significant interaction between the number of pinches and the PGRs for branches. For the plants pinched once, benzyladenine and dikegulac sodium reduced the number of branches compared to the control or ethephon groups. For plants pinched twice, benzyladenine or ethephon reduced the number of branches while dikegulac sodium had no significant effect compared to controls. Ethephon had no effect on branching in plants pinched once but reduced the number of branches in plants pinched twice.

At 9 weeks after the application of PGRs, the plants pinched once were 28% shorter than those pinched twice (Table 2.5, Figure 2.10). Average width was not significantly different between the once and twice pinched plants. There was no interaction between the number of pinches and PGR applied for height or average width. In the subplot, height was not significantly different between the PGR groups. Average width was reduced 11% by benzyladenine, 12% by ethephon, and 21% by dikegulac sodium when compared to the control.

The number of leaders was doubled in the plants pinched twice compared to the plants pinched once. There was a significant interaction between the number of pinches and PGR applications for leaders. For plants pinched once, there were no significant differences in number of leaders in response to PGR applications. In the plants pinched twice, all PGRs reduced the number of leaders as compared to the control plants. Ethephon resulted in the fewest number of leaders in the plants pinched twice. The number of branches was not significantly different between the pinched groups. For number of branches, there was no significant interaction between the number of pinches and branching PGRs. Benzyladenine and ethephon reduced the number of branches when compared to the control. Number of flower stalks were measured at the final data collection. A greater number of flower stalks were found in the plants pinched twice than in those pinched once. An interaction occurred between pinching and the PGRs for the number of flower stalks. Ethephon reduced the number of flower stalks in the plants pinched once. All PGRs reduced the number of flower stalks in the plants pinched twice, and ethephon had the fewest number of flower stalks.

Marketability was rated at 9 weeks after the PGR application. The twice pinched plants had a higher marketability rating than those pinched once (Table 2.5). There was no interaction between the number of pinches and PGRs applied. Only BA reduced the marketability rating relative to the controls. However, none of these plants were considered salable for the study. The average marketability rating for each group was in the 1-2 range, which is considered of poor quality and not salable. These plants were given such low ratings due to their leggy, non-upright growth habit, inability to fill out the pot, and straggly shoots and flower stalks. In order for a plant to receive high marketability ratings, it must have an upright but compact growth habit with tight internodes, many branches that fill out the container and give the plant a fuller appearance, and multiple, erect flower stalks with numerous flower buds.

As for flowering, plants pinched twice took longer to flower than those pinched once (Table 2.5). However, compared to the unpinched visual control, pinching nearly doubled the time for first open flower. There was no interaction for days to flower between the main plot and subplot. Days to flower were increased by benzyladenine or ethephon compared to the control and dikegulac sodium plants. There was no significant difference in shoot dry weight between the pinched groups or in the interaction between the plots. In the branching agent subplot, all of the PGRs reduced shoot dry weights as compared to the controls.

Discussion

Evaluating Branching Agent Applications on *Penstemon x mexicali* 'Pike's Peak Purple'

Height of 'Pike's Peak Purple' was reduced by benzyladenine or ethephon application, while average width was reduced by ethephon or dikegulac sodium application. Ethephon also reduced final shoot dry weight compared to the other groups. In other studies, ethephon was found to reduce shoot dry weight in ornamental crops like Jerusalem cherry (Khosh-Khui et al., 1979) and reduce flower dry weight in torch blanketflower (*Gaillardia pulchella* Foug.) (Hammond et al., 2007). All three branching agents increased branching at some point over the span of our experiment, but plants subjected to benzyladenine or ethephon had the most branches by the end of the experiment. Similarly, Currey and Erwin (2012) found that benzyladenine or ethephon increased branching in different *Kalanchoe* Adans. species.

Based on the results of the study, the concentration of dikegulac sodium may be increased in future experiments to determine its impact on increasing branching and growth control in *Penstemon*. Similar to our results, dikegulac sodium was found to not influence branching or height when applied to *Bouganvillea* Comm ex Juss. 'Rainbow Gold' (Norcini et al., 1992). However, application of dikegulac sodium at 800 or 1600 $mg{\cdot}L^{-1}$ increased branching in 'Limelight' hydrangea (*Hydrangea paniculata* (Siebold)) (Cochran et al., 2013).

The number of leaders in 'Pike's Peak Purple' did not differ between any of the PGR applications until the final data collection, where plants sprayed with ethephon had fewer leaders. This reduction in leaders may be due to the increased number of branches that we observed but were not yet fully mature enough to be classified as leaders in ethephon sprayed plants. Flowering was delayed and decreased in the ethephon application, which most likely is attributed to the ethylene gas mode of action within the plant preventing initiation of flowering buds (Pilon, 2006). Although ethephon was found to cause flower delays and is known to promote flower abortion, it does show promise as a possible PGR for enhancing branching of *Penstemon*. Ethephon contributed to increased flower abortion in *Lagerstroemia fauriei* Koehne x 'Tuscarora' but also increased the number of lateral branches as a result (Fain et al., 2001). Benzyladenine, however, increased the number of 'Pike's Peak Purple' flower stalks, and so may have the potential of promoting flowering in this particular crop. Benzyladenine enhanced flowering in other floriculture crops including 'Moonbeam' Coreopsis (*Coreopsis verticillata* L.) (Farris et al., 2009). Overall, growth control and increases in branching were seen in the branching agent applications. In addition to having the potential as a branching agent, ethephon may also be considered for use as a growth retardant in regulating growth for this particular *Penstemon*. Ethephon was effective at reducing height and width index in vegetative annuals (Starman et al., 2004).

Despite the effects seen with the different PGRs applied, further manipulation and control of growth is necessary to produce a more marketable and better quality containerized 'Pike's Peak Purple' crop for the industry. The plants produced by the end of this experiment were not salable due to the presence of apical dominance occurring in the main shoot. Apical dominance is a term used to describe how lateral buds are prevented from growing into lateral branches due to the terminal or apical bud (Carey et al., 2009). The increase in lateral branches from the PGR applications only occurred on this main shoot, which resulted in a non-upright plant that did not fill up the pot completely. In order to produce a more marketable plant, apical dominance would need to be inhibited to allow for more growth of lateral branches near the base of the plant. An increase in lateral branches at the base of the plant would provide a fuller appearance in the container. A fuller plant with more branches is favored by more consumers (Cole et al., 2013). Mechanical methods such as pinching may be necessary in breaking this apical dominance and promoting an early increase in branches for 'Pike's Peak Purple' in addition to the application of branching PGRs.

Evaluating Branching Agents and Pinching on *Penstemon* 'Pike's Peak Purple'

Applying two pinches to 'Pike's Peak Purple' helped to regulate growth longer and produce more marketable plants than by only applying one pinch. Plants pinched twice were shorter and more compact than plants pinched once early in the experiment. These results agree with a study done by Rezazadeh and Harkess (2015) who found that two pinches resulted in a greater reduction in height when compared with one or no pinch for purple firespike (*Odontonema callistachyum*). Ryagi et al. (2007) also found that two pinches significantly reduced height of carnation (*Dianthus caryophyllus L.*) more than one pinch. The plants pinched twice maintained an upright growth habit for a longer period of time than those pinched once. The once pinched groups quickly outgrew their pinch treatment, which resulted in a disorderly growth habit that was not ideal for salability. The additional application of plant growth regulators encouraged more compact and shorter plants early on, especially in those pinched twice, but the plants outgrew these applications by the end of the study. It is interesting to note that the PGRs, especially ethephon, were more responsive at controlling growth in plants pinched twice than in plants pinched once.

Although the combination of the branching agents and pinching treatments did not increase branching when compared to the pinched controls, it was effective at increasing branching compared to the unpinched control (Table 2.5). In a similar study, the application of dikegulac sodium to unpinched and pinched flame azaleas (*Rhododendron calendulaceum* (Michx.) Torr) resulted in an increase in lateral branches compared to unpinched or pinched plants that did not receive a chemical application (Malek et al., 1992). Application of benzyladenine reduced branching significantly when compared to the pinched controls. Our results differ from another study where application of benzyladenine increased lateral shoots more than heading treatments in apple trees (*Malus domestica* Borkh) (Zamanipour et al., 2012). For this particular Penstemon, more than one application of these PGRs may be necessary in promoting more branching. In the previous experiment, two applications of PGRs, one in the liner stage and again after transplant, were effective at increasing branching. In this study, however, one application alone in the liner stage was not enough to increase branching. Grossman et al. (2013) found that two applications of PGRs, one in the liner stage and again after transplant, were more effective than one application in the liner stage in increasing branching of several herbaceous perennials. In this second *Penstemon* study, application of the PGRs actually reduced branching. There are a few possibilities that could account for these differences in plant growth between the two studies. One possible reason is that the experiments occurred at different times of the year. The first experiment occurred in the winter, while the second experiment occurred in the summer. The differences in seasons and in DLI could account for the differing growth responses to the PGRs. Another possible reason is that the relative humidity at the time of the PGR application was much higher (86%) in the second experiment than in the first experiment (33% or 44%). This high relative humidity may have caused more

PGR to be taken up by the plant. As a result, these PGRs contributed to more growth control than branching, which was seen at 2 WAT (Figure 2.5). These differences suggest possible answers to the varying PGR effects between the first and second experiment.

The most marketable plants were seen at 6 weeks after the application of PGRs and were produced in the plants that were pinched twice (Figure 2.9). These plants were well branched, compact, and shorter than the unpinched control and once pinched control. Although these plants did not yet have flower stalks, they did have potential for being sold in the industry as vegetative plants. However, once the flower stalks were produced, all of the groups were reduced in quality and marketability. The plants became straggly and leggy and were not able to hold the flower stalks upright. Plants with this kind of growth habit have reduced marketability and probably are not saleable (Richards and Wilkinson, 1984). If growers intend to hold 'Pike's Peak Purple' in a container for a longer period of time or until the time of flowering, then further growth control is necessary in order to produce an acceptable and salable plant.

It is clear that pinching helps regulate growth of 'Pike's Peak Purple' while in the container, but additional growth regulation will be required in order to maintain a more upright and erect growth habit by the time the plants begin to flower and are considered finished. Pinching during the liner stage promoted early lateral bud growth and helped to reduce apical dominance (Starman, 1991), and so should be recommended for early growth control of 'Pike's Peak Purple.' This first pinch of the study helped to break early apical dominance and enhance lateral bud formation. In a study by Phetpradap et al. (1994), lateral branching was enhanced by applying a pinch treatment to dahlias when there were 6-7 pairs of leaves (*Dahlia pinnata x Dahlia coccinea* Cav.). Although the second pinch was also effective at further controlling growth, an alternative method may be used as a substitute because mechanical methods such as pinching may not be cost-effective due to how much labor is required to control the growth of these plants (Cole et al., 2013). One alternative method to pinching a second time would be to apply a growth retardant in addition to a PGR branching agent. A plant growth retardant is type of PGR that functions primarily for height control (Latimer, 2004). These growth retardants may be able to further regulate growth and even help eliminate having to pinch or prune plants all together (Duck et al., 2004). Plant growth retardants offer the possibility of not only reducing growth in floriculture crops but also reducing labor costs associated with manual pruning and pinching. Future studies will examine the effects of combinations of pinching, branching agents, and growth retardants on the container growth of 'Pike's Peak Purple.' The goal is to find the best possible combination of these growth regulation methods for encouraging a better quality, more manageable, and highly marketable containerized *Penstemon x mexicali* for the industry.

Overall, the results of the preliminary branching study showed that two applications of branching agents like benzyladenine and ethephon are effective at increasing branching in 'Pike's Peak Purple.' The results of the combined pinching and branching study found that pinching applications are beneficial in regulating growth. Although the PGRs were not efficient at increasing branching, their applications contributed to promoting a shorter and more compact appearance. Based on the outcome of these studies, we are able to make the conclusions that two applications of PGRs are more beneficial at affecting plant growth and branching than one application, and that pinching treatments are effective at controlling growth of 'Pike's Peak Purple.'

Literature Cited

Cochran, D.R., A. Fulcher, and G. Bi. 2013. Efficacy of dikegulac sodium applied to pruned and unpruned 'Limelight' hydrangea grown at two locations in the southeastern United States. HortTechnology 23(6): 836-842.

Cole, J.C., R.O. Brown, and M.E. Payton. 2013. Two cultivars of oakleaf hydrangea respond to ancymidol, uniconazole, or pinching. HortTechnology 23(3): 339-346.

Carey, D., W. Buhler, and B. Whipker. 2009. Stimulating plant growth. Greenhouse Product News 9:20-22.

Currey, C.J. and J.E. Erwin. 2012. Foliar applications of plant growth regulators affect stem elongation and branching of 11 Kalanchoe species. HortTechnology 22(3):338-344.

Duck, M.W., B.M. Cregg, R.T. Fernandez, R.D. Heins, and F.F. Cardoso. 2004. Height control of Picea spp. and *Chamaecyparis lawsoniana* with uniconazole and 6-benzyladenine. J. Environ. Hort. 22(3): 165-169.

Fain, G.B., C.H. Gilliam, and G.J. Keever. 2001. Response of Lagerstroemia x 'Tuscarora' to Pistill and Atrimmec. J. Environ. Hort. 19(3): 149-152.

Farris, M.E., G.J. Keever, J.R. Kessler, and J.W. Olive. 2009. Benzyladenine and cyclanilide promote shoot development and flowering of 'Moonbeam' Coreopsis. J. Environ. Hort. 27(3):176-182.

Glady, J.E., N.S. Lang, and E.S. Runkle. 2007. Effects of ethephon on stock plant management of *Coreopsis verticillata*, *Dianthus caryophyllus*, and *Veronica longifolia*. HortScience 42(7):1616-1621.

Grossman, M., J. Freeborn, H. Scoggins, and J. Latimer. 2012. Benzyladenine increases branching but reduces root growth of herbaceous perennial liners. HortScience 47(8):1085-1090.

Grossman, M., J. Freeborn, H. Scoggins, and J. Latimer. 2013. Timing of benzyladenine and dikegulac sodium application affects branching of liners and finished herbaceous perennial plants. HortScience 48(7):875-882.

Hammond, H.E., R.K. Schoellhorn, S.B. Wilson, and J.G. Norcini. 2007. Differing blanketflower cultivar and ecotype responses to plant growth regulators. HortTechnology 17(4):552-556.

Horn, Maurice. 2005. Pick of the penstemons. Horticulture 102(5):50-53.

Khosh-Khui, M., Rouhani, I., and Shaybany, B. 1979. Response of Jerusalem cherry to growth regulators. Can. J. Plant Sci. 59: 75-79.

Latimer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Plant Growth Regulat. Soci. Amer. 31:1-4.

Latimer, J. and J. Freeborn. 2009. New Uses of PGRs in ornamentals: Configure (6-BA) increases branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 36:88-93.

Latimer, J. and J. Freeborn. 2010. Branching enhancers, Configure (6-BA) and Augeo (dikegulac sodium), affect branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 37:148-152.

Lindgren, D. and E. Wilde. 2003a. The descriptions of Penstemon species and their cultivars, p.7-97. In: Growing Penstemons: Species, cultivars and hybrids. Infinity, Haverford, P.A.

Lindgren, D. and E. Wilde. 2003b. Background and history of penstemons and the American Penstemon Society, p.1-4. In: Growing Penstemons: Species, cultivars and hybrids. Infinity, Haverford, P.A.

Malek, A.A., F.A. Blazich, S.L. Warren, and J.E. Shelton. 1992. Growth response of seedlings of flame azalea to manual and chemical pinching. J. Environ. Hort. 10(1): 28-31.

Neff, M. 2013. How to grow and sell Penstemon. Greenhouse Grower. 13 January 2014. <http://www.greenhousegrower.com/uncategorized/how-to-grow-and-sell-penstemon/>.

Norcini, J.G., J.M. McDowell, and J.H. Aldrich. 1992. Effect of dikgeulac on flowering and growth of *Bouganvillea* 'Rainbow Gold.' HortScience 27(1):35-36.

Phetpradap, S., J.G. Hampton, and M.J. Hill. 1994. Effect of hand pinching and plant growth regulators on seed production of field grown hybrid dahlia. N.Z. J. Crop and Hort. Science 22: 313-320.

Pilon, P. 2006. Controlling plant height of perennial crops, p.201-248. In: Perennial solutions: A grower's guide to perennial production. Ball, Batavia, IL.

Rezazadeh, A. and R.L. Harkess. 2015. Effects of pinching, number of cuttings per pot, and plant growth regulators on height control of purple firespike. HortTechnology 25(1): 2015.

Richards D. and Wilkinson, R.I., 1984. Effect of manual pinching, potting-on and cytokinins on branching and flowering of *Camellia, Rhododendron* and *Rosa*. Sci. Hortic. 23: 75-83.

Ryagi, V.Y., S.M. Mantur, and B.S. Reddy. 2007. Effect of pinching on growth, yield and quality of flowers of Carnation varieties grown under polyhouse. Karnataka J. Agric. Sci. 20(4): 816-818.

Starman, T.W. 1991. Response of Kientzler New Guinea impatiens to manual and chemical pinching. HortScience 26(7): 856-857.

Starman, T.W., M.C. Robinson, and K.L. Eixmann. 2004. Efficacy of ethephon on vegetative annuals. HortTechnology 14(1): 83-87.

Zamanipour, M., E.Ganji Moghadam, and A. Asgharzade. 2012. The effects of heading and benzyladenine applications on branching of apple (cvs. 'Red Delicious' and 'Golden Delicious') trees in nursery. African J. Agricultural Research 7(30): 4297-4304.

Table 2.1. Plant height, average width, and numbers of branches of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at 4 or 6 weeks after initial plant growth regulator (PGR) foliar spray applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac). Phytotoxicity ratings at 4 weeks after initial application; 2 weeks after the second PGR application.

	4 weeks after initial PGR				6 weeks after initial PGR		
PGR (mg•L^{-1})	Plant height (cm)	Plant width (cm)	Number of branches	Phytotoxicity rating	Plant height (cm)	Plant width (cm)	Number of branches
Control	16.8a[z]	13.6a	20.0b	0.0b	26.6a	16.8a	31.6bc
Benzyladenine 600	15.1b	13.9a	19.3b	1.8a	25.4a	16.7a	28.9c
Ethephon 500	12.1c	10.8b	25.4a	1.5a	19.4b	12.3b	36.8a
Dikegulac 400	16.9a	14.4a	22.9a	0.2b	27.0a	18.1a	34.4ab
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001
LSD	1.2	1.2	2.5	0.7	3.3	1.8	2.9

[z]Means within a column followed by the same letter are not significantly different (Student’s t-test, $p<0.05$, n=8).

Table 2.2. Plant height, average width, numbers of leaders and branches, flowering response, and shoot dry weight of *Penstemon* x *mexicali* 'Pike's Peak Purple' at 9 weeks after initial plant growth regulator (PGR) foliar spray applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac).

	9 weeks after initial PGR application								
PGR (mg·L^{-1})	Plant height (cm)	Flower stalk height (cm)	Plant width (cm)	Number of leaders	Number of branches	Days to flower	Percent plants flowering (%)	Number of flower stalks	Shoot dry weight (g)
Control	18.3	45.2a[z]	34.0a	15.6a	94b	47.1bc	100	1.7b	9.09a
Benzyladenine 600	20.6	44.1a	34.8a	14.6ab	126a	49.9b	100	10.3a	8.73a
Ethephon 500	17.1	34.9b	29.3b	12.0b	114a	55.3a	43	1.0b	5.63b
Dikegulac 400	21.0	42.7a	29.4b	16.7a	87b	44.7c	86	1.1b	8.26a
P-value	0.1233	<0.0001	<0.0001	0.0128	0.0002	0.0014	0.0119	<0.0001	<0.0001
LSD	3.7	--[y]	2.6	2.8	16.7	--	--	3.4	1.01

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $p<0.05$, $n=8$)
[y]Flowering LSD data not available due to not all of the plants flowering in the dikegulac and ethephon groups.

Table 2.3. Plant height, average plant width, numbers of leaders and branches, and phytotoxicity rating of *Penstemon x mexicali* 'Pike's Peak Purple' as measured at 2 weeks after PGR applications. Plants were pinched once (liner stage) and subjected to foliar applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac) compared to an untreated control (None). Data were collected prior to the second pinch. Data analyzed using a split-plot design and ANOVA.

Pinch/PGR	Plant height (cm)	Plant width (cm)	Number of leaders	Number of branches	Phytotoxicity Rating
Unpinched control	21.4	14.8	1.0	14.3	0.0
Pinched					
Once	7.5	10.2	1.9	7.7	0.9
Branching agent (mg·L^{-1})					
None	9.6a[z]	13.0a	1.7b	7.5b	0.0c
Benzyladenine 600	6.8b	8.9c	1.3b	7.1b	1.8a
Ethephon 500	5.4c	8.4c	1.8b	7.3b	0.9b
Dikegulac 600	8.5a	10.5b	2.9a	8.8a	1.3b
PGR effect	<0.0001	<0.0001	<0.0001	0.0177	<0.0001
LSD	1.1	0.9	0.5	1.1	0.5
Pinch*PGR effect	0.6287	0.9082	0.8122	0.8480	0.0640

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $p<0.05$, n=8)

Table 2.4. Plant height, average plant width, and numbers of leaders and branches of *Penstemon x mexicali* ‘Pike’s Peak Purple’ as measured at 4 or 6 weeks after PGR applications. Plants were pinched once (liner stage) or twice (liner stage and after transplant) and subjected to foliar applications of benzyladenine, ethephon, and dikegulac sodium (dikegulac) compared to an untreated control (None). Data analyzed using a split-plot design and ANOVA.

	4 weeks				6 weeks					
Pinch/PGR	Plant height (cm)	Plant width (cm)	Number of leaders	Number of branches	Plant height (cm)		Plant width (cm)	Number of leaders	Number of branches	
Unpinched control	42.5	16.4	1.4	23.9	51.0		25.7	1.3	26.5	
Pinched										
Once	18.7	21.6	3.7	33.3	29.1		35.5	3.9	46.7	
Twice	11.7	14.7	5.0	33.0	23.7		28.1	4.4	29.8	
Pinch effect	<0.0001	<0.0001	<0.0001	0.8772	<0.0001		<0.0001	0.0915	<0.0001	
LSD	1.8	1.7	0.6	4.9	--[y]		--	--	--	
Branching agent ($mg \cdot L^{-1}$)					once	twice			once	twice
None	18.1a[z]	22.0a	5.2a	38.9a	35.4a	27.3a	35.1a	5.1a	61.6a	38.6a
Benzyladenine 600	13.9b	17.1c	3.4c	24.6c	25.8b	23.5b	31.2bc	3.4b	37.3b	20.9c
Ethephon 500	12.3b	15.0d	4.3b	36.2ab	29.6ab	20.0c	29.1c	3.9b	51.6a	26.9bc
Dikegulac 600	16.6a	18.6b	4.4b	32.8b	25.7b	24.1ab	31.8b	4.1b	36.1b	32.6ab
PGR effect	<0.0001	<0.0001	0.0002	<0.0001	0.0077	0.0018	0.0004	0.0006	0.0029	0.0002
LSD	3.2	3.0	0.8	5.8	--	--	--	--	--	--
Pinch*PGR effect	0.3232	0.0886	0.7591	0.1348	0.0396		0.6508	0.5724	0.0413	

[z]Means within a column followed by the same letter are not significantly different (Student’s t-test, $p<0.05$, n=8)
[y]Six week LSD data not available due to a plant death in the twice pinched, dikegulac sodium group.

Table 2.5. Plant height, average plant width, numbers of leaders, branches, and flower stalks, marketability rating, days to flower, and shoot dry weight of *Penstemon x mexicali* ‘Pike’s Peak Purple’ as measured at 9 weeks after PGR applications. Plants were pinched once (liner stage) or twice (liner stage and after transplant) and subjected to foliar applications of benzyladenine, ethephon, and dikegulac sodium (dikegulac) compared to an untreated control (None). Data analyzed using a split-plot design and ANOVA.

Pinch/PGR	Plant Height (cm)	Plant Width (cm)	Number of Leaders		Number of Branches	Number of Flower Stalks		Marketability Rating[x]	Days to Flower[w]	Shoot Dry Weight (g)
Unpinched control	51.3	49.1	12.4		63.4	11.8		2.0	23.4	15.0
Pinched										
Once	22.7[z]	53.0	5.2		88.6	4.6		1.9	44.7	15.0
Twice	31.7	53.0	12.8		84.1	9.7		2.4	50.7	15.4
Pinch effect	0.0009	0.9913	<0.0001		0.3256	<0.0001		<0.0001	<0.0001	0.5951
Branching agent ($mg \cdot L^{-1}$)			once	twice		once	twice			
None	28.7	59.7a[y]	5.8	16.4a	99.1a	5.6	13.3a	2.4a	44.8b	18.8a
Benzyladenine 600	22.1	53.1b	5.0	12.5b	78.9b	4.4	10.3b	1.9b	50.4a	14.1b
Ethephon 500	27.8	52.4bc	4.4	9.9c	81.1b	4.0	6.8c	2.1ab	50.0a	13.4b
Dikegulac 600	30.1	47.0c	5.9	12.6b	86.4ab	4.3	8.5bc	2.1ab	45.4b	14.4b
PGR effect	0.1417	0.0006	0.2202	0.0003	0.0131	0.0937	<0.0001	0.0476	<0.0001	<0.0001
Pinch*PGR effect	0.3031	0.2705	0.0086		0.1533	0.0056		0.3995	0.0858	0.3351

[z]Plants pinched once had shorter heights than plants pinched twice due to not being upright and having a leggy growth habit.
[y]Means within a column followed by the same letter are not significantly different (Student’s t-test, p<0.05, n=8)
[x]Marketability was evaluated and rated on the following scale: 0.) Death, not salable 1.) Unacceptable/extremely poor quality, unsalable 2.) Poor quality, unsalable 3.) Okay/fair quality, some salability 4.) Good quality, salable 5.) Excellent/ideal quality, salable
[w]Days to flower were measured from the day of transplant to the day of first open flower.

Figure 2.1. *Penstemon x mexicali* 'Pike's Peak Purple' liners at the time of application of the initial foliar PGR treatments (0 WAIT).

Figure 2.2. *Penstemon x mexicali* 'Pike's Peak Purple' liners displaying phytotoxicity symptoms one week after the first initial foliar application. Liners treated with benzyladenine (left) exhibiting red discoloration on leaves, and liners treated with ethephon (right) exhibiting twisting of leaves.

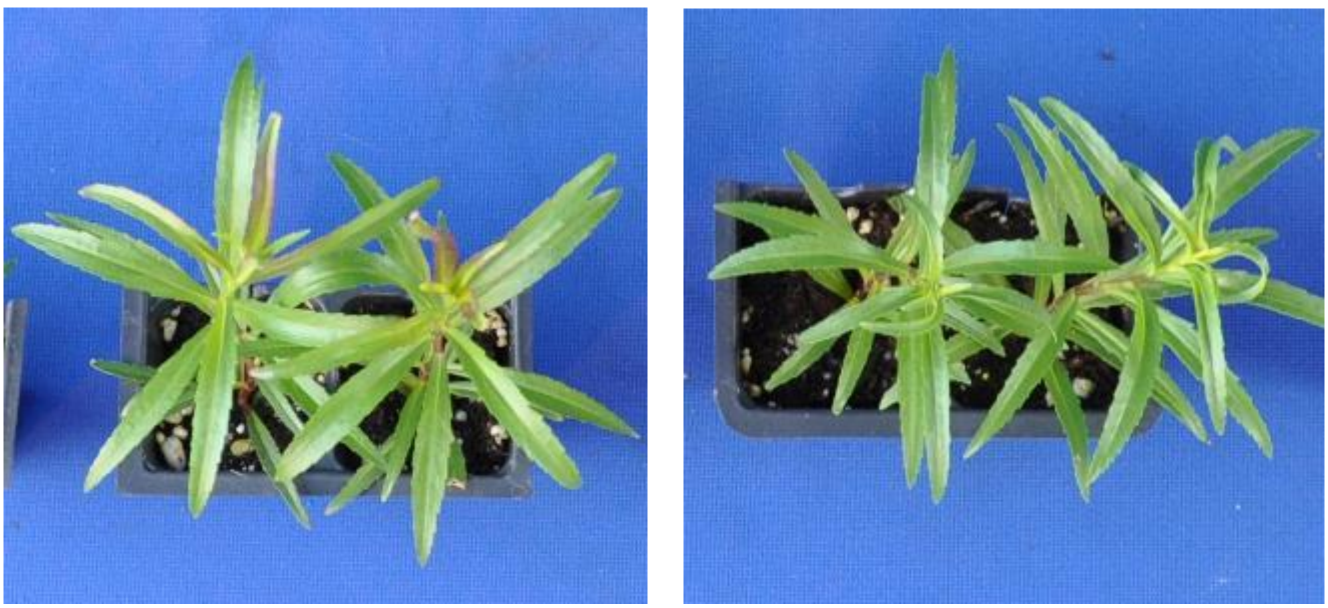
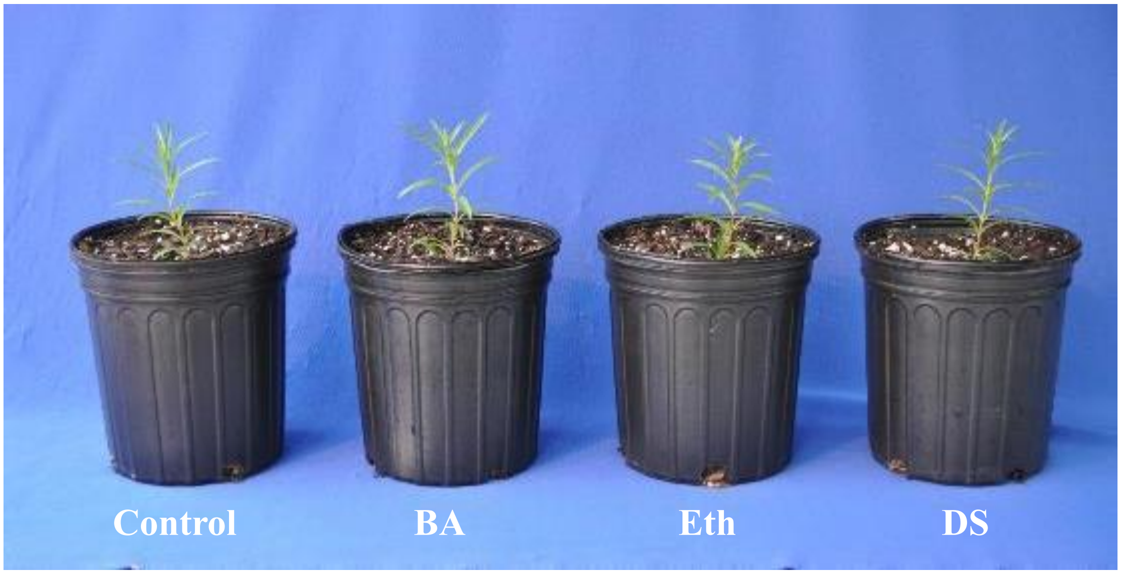


Figure 2.3. *Penstemon x mexicali* 'Pike's Peak Purple' A. Liners at the time of the first pinching application (top photo, left) and at the time of application of the foliar PGR treatments (top photo, right). The liner to the left has not been pinched, while the liner to the right has been pinched and only has five nodes/five sets of leaves remaining. B. Plants at the time of the second pinching application (bottom photo). The first plant to the left has not been pinched, the plant in the middle was pinched once during the liner stage (1P), and the last plant to the right has been pinched twice (2P), once in the liner and once after transplant.

Figure 2.4. *Penstemon x mexicali* ‘Pike’s Peak Purple’ liners displaying phytotoxicity symptoms 1 week after PGR foliar application. Liners treated with benzyladenine (picture 1) exhibiting red/purple discoloration on leaves, liners treated with ethephon (picture 2) exhibiting twisting of leaves, and liners treated with dikegulac sodium (picture 3) exhibiting chlorosis on young shoots.

Figure 2.5. *Penstemon x mexicali* 'Pike's Peak Purple' (left to right): untreated control, benzyladenine (BA) at 600 mg/L-1, ethephon (Eth) at 500 mg/L-1, and dikegulac sodium (DS) at 400 mg/L-1. Top photo: plants at 2 weeks after the initial foliar PGR application (2 WAIT) and at the time of the second foliar application. Bottom photo: Plants at 4 weeks after the initial foliar PGR application and 2 weeks after the second foliar application.



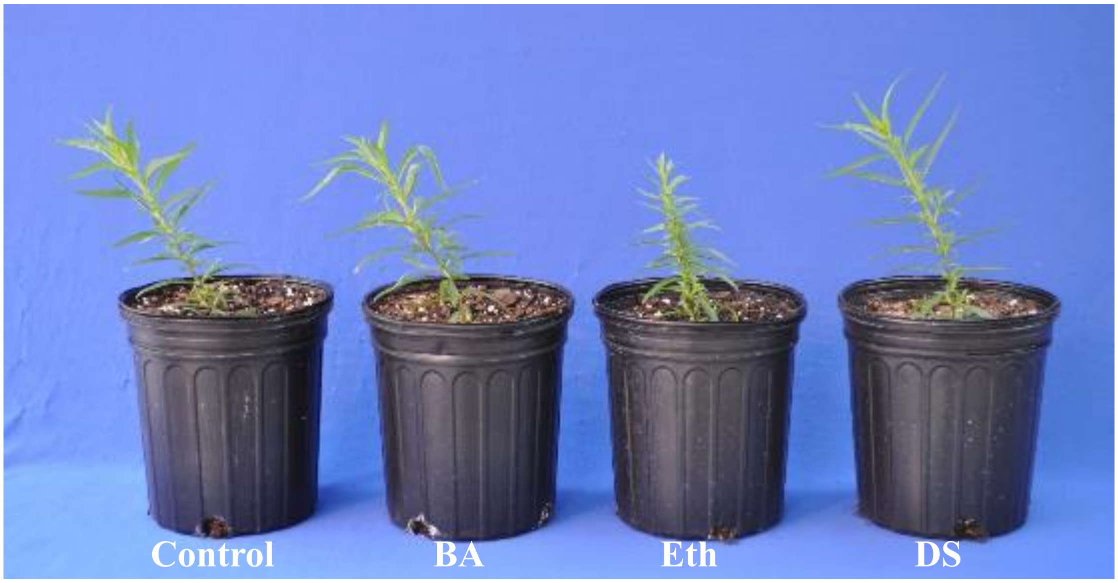


Figure 2.6. *Penstemon x mexicali* ‘Pike’s Peak Purple’ (left to right): untreated control, benzyladenine (BA) at 600 mg/L-1, ethephon (Eth) at 500 mg/L-1, and dikegulac sodium (DS) at 400 mg/L-1. Top photo: Plants at 6 weeks after the initial foliar PGR application and 4 weeks after the second foliar application. Middle photo: Plants at 9 weeks after the initial foliar PGR application and 7 weeks after the second foliar application. Bottom photo: Plants at 11 weeks after the initial foliar PGR application and 9 weeks after the second foliar application.

Figure 2.7. *Penstemon x mexicali* ‘Pike’s Peak Purple’ (left to right): unpinched control, 1 pinch control (1pControl), 1 pinch benzyladenine (1pBA) at 600 mg/L-1, 1 pinch ethephon (1pEth) at 500 mg/L-1, and 1 pinch dikegulac sodium (1pDS) at 600 mg/L-1 plants after first pinch and at 2 weeks after the time of the foliar PGR application but before the application of the second pinching treatment.

Figure 2.8. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 4 weeks after the time of the foliar PGR applications. The top picture shows the treatment groups that have been pinched once: unpinched control, 1 pinch control (1pControl), 1 pinch benzyladenine (1pBA) at 600 mg/L^{-1}, 1 pinch ethephon (1pEth) at 500 mg/L^{-1}, and 1 pinch dikegulac sodium (1pDS) at 600 mg/L^{-1}, while the bottom picture shows the treatment groups that have been pinched twice: : unpinched control, 2 pinch control (2pControl), 2 pinch benzyladenine (2pBA) at 600 mg/L^{-1}, 2 pinch ethephon (2pEth) at 500 mg/L^{-1}, and 2 pinch dikegulac sodium (2pDS) at 600 mg/L^{-1}.

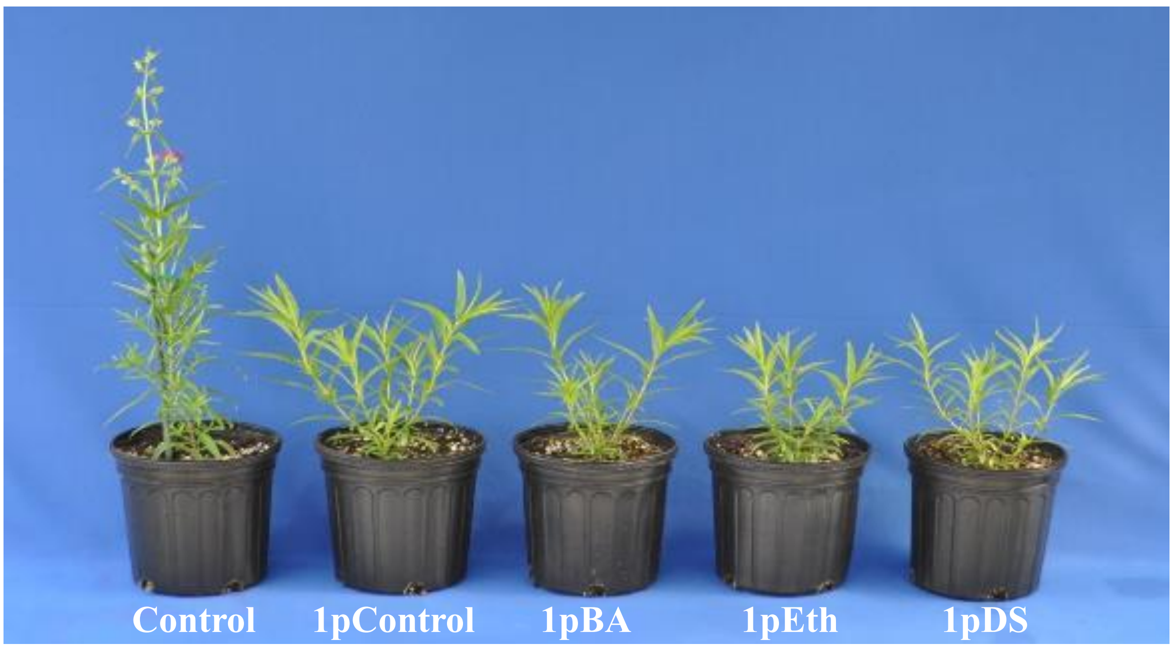


Figure 2.9. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 6 weeks after the time of the foliar PGR applications. The top picture shows the treatment groups that have been pinched once: unpinched control, 1 pinch control (1pControl), 1 pinch benzyladenine (1pBA) at 600 mg/L^{-1}, 1 pinch ethephon (1pEth) at 500 mg/L^{-1}, and 1 pinch dikegulac sodium (1pDS) at 600 mg/L^{-1}, while the bottom picture shows the treatment groups that have been pinched twice: : unpinched control, 2 pinch control (2pControl), 2 pinch benzyladenine (2pBA) at 600 mg/L^{-1}, 2 pinch ethephon (2pEth) at 500 mg/L^{-1}, and 2 pinch dikegulac sodium (2pDS) at 600 mg/L^{-1}.

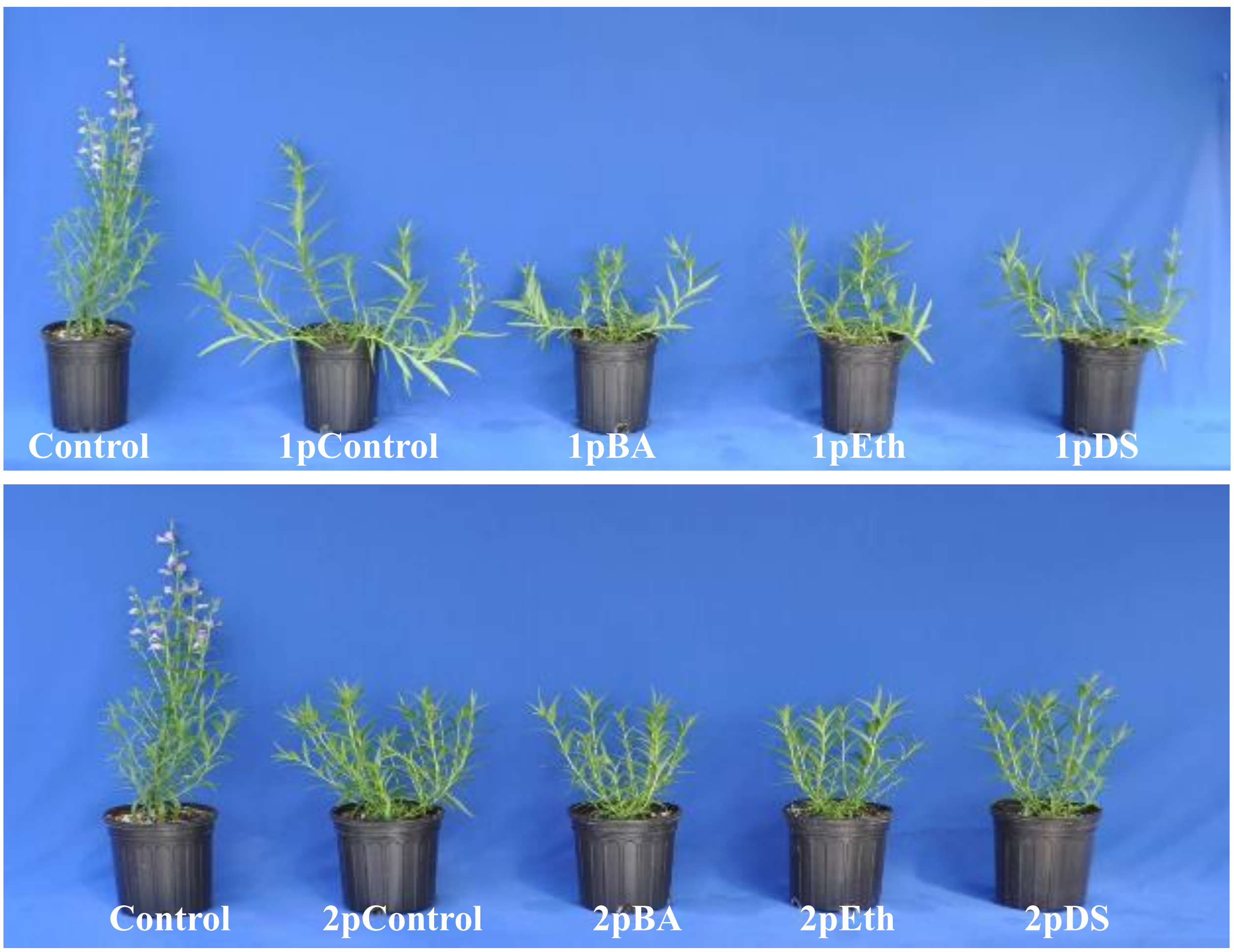
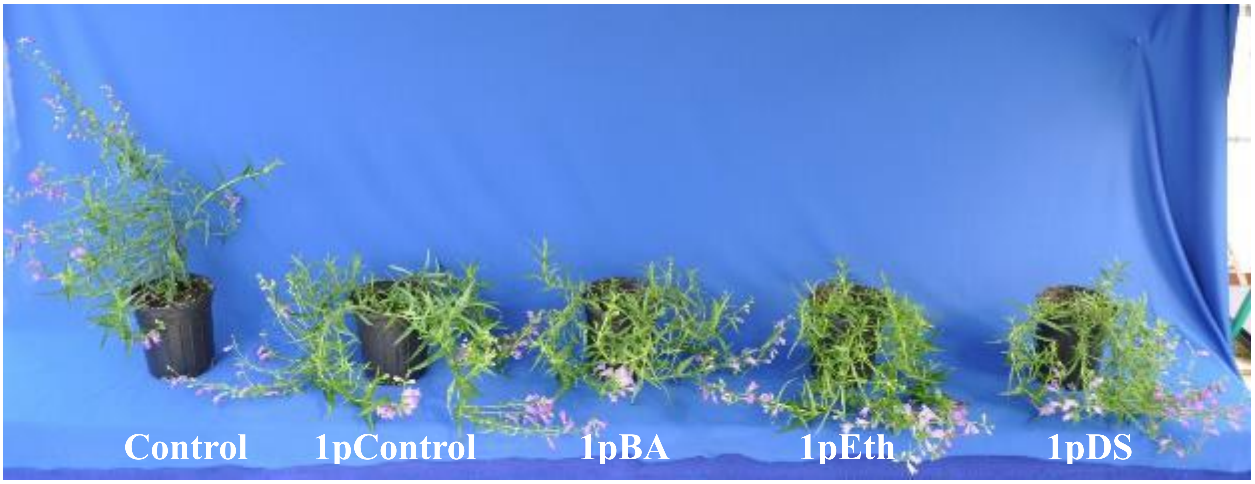
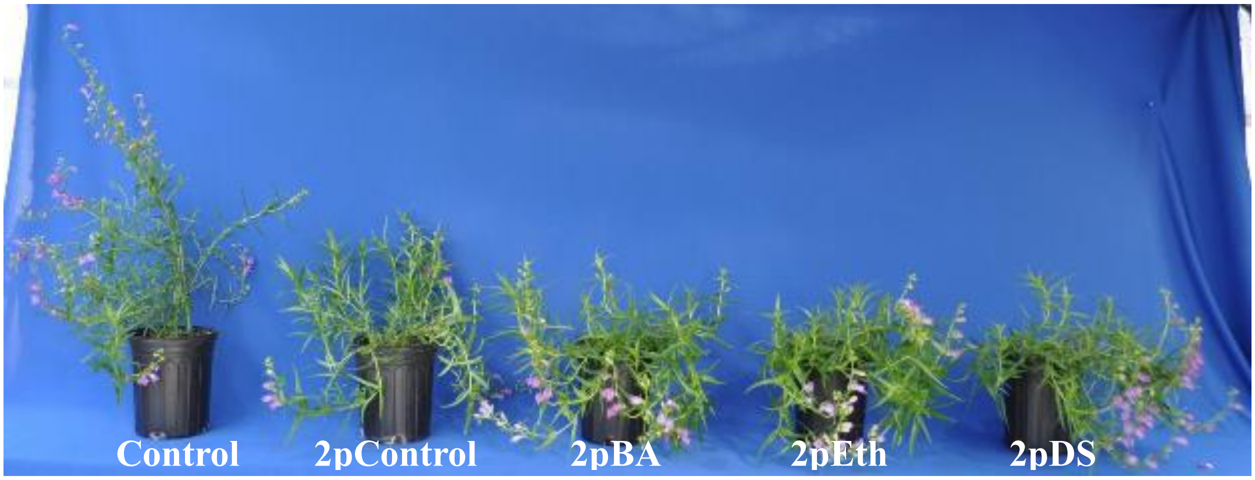


Figure 2.10. *Penstemon x mexicali* 'Pike's Peak Purple' plants at 9 weeks after the time of the foliar PGR applications. The top picture shows the treatment groups that have been pinched once: unpinched control, 1 pinch control (1pControl), 1 pinch benzyladenine (1pBA) at 600 mg/L^{-1}, 1 pinch ethephon (1pEth) at 500 mg/L^{-1}, and 1 pinch dikegulac sodium (1pDS) at 600 mg/L^{-1}, while the bottom picture shows the treatment groups that have been pinched twice: : un-pinched control, 2 pinch control (2pControl), 2 pinch benzyladenine (2pBA) at 600 mg/L^{-1}, 2 pinch ethephon (2pEth) at 500 mg/L^{-1}, and 2 pinch dikegulac sodium (2pDS) at 600 mg/L^{-1}.





Appendix A

Appendix

Table A.1 Plant height, average width, number of leaders and branches of Penstemon x mexicali 'Pike's Peak Purple at 0, 2, or 4 weeks after initial plant growth regulator (PGR) foliar spray applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac).

	0 week			2 weeks				4 weeks			
	Plant height	Plant width		Plant height	Plant width	Number of		Plant height	Plant width	Number of	
PGR ($mg \cdot L^{-1}$)	(cm)	(cm)	Shoot dry weight (g)	(cm)	(cm)	leaders	branches	(cm)	(cm)	leaders	branches
Control	6.7	6.9	0.132c[z]	9.1	8.7	1.0	0.0b	16.8a	13.6a	1.0	20.0b
Benzyladenine 600	6.5	6.7	0.137bc	8.9	9.1	1.0	1.3a	15.1b	13.9a	1.0	19.3b
Ethephon 500	6.8	6.9	0.154b	8.5	9.0	1.0	0.0b	12.1c	10.8b	1.0	25.4a
Dikegulac 400	6.7	7.2	0.175a	9.3	9.0	1.0	0.0b	16.9a	14.4a	1.0	22.9a
P-value	0.8968	0.6015	0.0004	0.2482	0.3694	--[y]	<0.0001	<0.0001	<0.0001	--	<0.0001
LSD	0.7	0.8	0.02	0.8	0.6	--	0.5	1.2	1.2	--	2.5

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $p<0.05$, $n=8$); Note: At 0 week, all plants had one leader and no branches.
[y]P-value and LSD data not available due to no difference in number of leaders between PGR groups.

Table A.2. Plant height, average width, number of leaders and branches of Penstemon x mexicali 'Pike's Peak Purple at 6 weeks after initial plant growth regulator (PGR) foliar spray applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac). Phytotoxicity ratings at 1, 2, and 4 weeks after initial PGR application.

	6 weeks after initial PGR application						
	Plant height	Plant width	Number of		Phytotoxicity rating		
PGR ($mg \cdot L^{-1}$)	(cm)	(cm)	leaders	branches	1 wk	2 wk	4 wk
Control	26.6a[z]	16.8a	1.1	31.6bc	0.0c	0.0b	0.0b
Benzyladenine 600	25.4a	16.7a	1.0	28.9c	1.3b	1.3a	1.8a
Ethephon 500	19.4b	12.3b	1.0	36.8a	2.0a	1.8a	1.5a
Dikegulac 400	27.0a	18.1a	1.0	34.4ab	0.0c	0.0b	0.3b
P-value	0.0001	<0.0001	0.4074	<0.0001	<0.0001	<0.0001	<0.0001
LSD	3.3	1.8	0.2	2.9	0.3	0.6	0.7

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $p<0.05$, $n=8$)

Table A.3. Plant height, flower stalk height, average width, number of leaders and branches, flowering data and shoot dry weight of Penstemon x mexicali 'Pike's Peak Purple' at 9 weeks after initial plant growth regulator (PGR) foliar spray applications of benzyladenine, ethephon, or dikegulac sodium (dikegulac).

	9 weeks after initial PGR application								
				Number of					
PGR ($mg \cdot L^{-1}$)	Plant height (cm)	Flower stalk height (cm)	Plant width (cm)	leaders	branches	Days to flower	Number of flower stalks	Percent plants flowering (%)	Shoot dry weight (g)
Control	18.3	45.2a[z]	34.0a	15.6a	94b	47.1bc	1.7b	100	9.09a
Benzyladenine 600	20.6	44.1a	34.8a	14.6ab	126a	49.9b	10.3a	100	8.73a
Ethephon 500	17.1	34.9b	29.3b	12.0b	114a	55.3a	1.0b	43	5.63b
Dikegulac 400	21.0	42.7a	29.4b	16.7a	87b	44.7c	1.1b	86	8.26a
P-value	0.1233	<0.0001	<0.0001	0.0128	0.0002	0.0014	<.0001	0.0119	<.0001
LSD	3.7	--[y]	2.6	2.8	16.7	--	3.4	--	1.01

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $p<0.05$, n=8)
[y]Flowering LSD data not available due to not all of the plants flowering in the dikegulac and ethephon groups.

Chapter 3: Evaluation of Plant Growth Retardants on *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple'

Introduction

Greenhouse and nursery growers are faced with challenges when managing the growth of herbaceous perennials and other floriculture crops in containers. Height control is a central issue because the quality of the product is often reduced when plants are overgrown in their container. So, it is crucial that growers find the proper balance of plant size and container size in order to maintain quality of the product for consumers (Kessler and Keever, 2008). Plant growth regulators or PGRs provide an effective means to improve quality of container crops by altering their growth habit and promoting compactness. PGRs known as plant growth retardants such as paclobutrazol and uniconazole affect plant growth by acting as gibberellin biosynthesis inhibitors; i.e., they block the gibberellic pathway and prevent synthesis from occurring (Latimer, 2004). These gibberellin inhibitors are effective at controlling plant height in many ornamental crops in the greenhouse industry. Overall, floriculture research continues to benefit both greenhouse and nursery growers in improving overall plant quality of their crops by determining and evaluating how these gibberellin inhibitors affect the growth of plants and whether they can be applied safely and appropriately in the industry.

Foliar spray concentrations of paclobutrazol or uniconazole ranging from 10 to 160 $mg \cdot L^{-1}$ were effective at reducing the size of four different bedding plant species, especially as the concentrations increased (Barrett and Nell, 1992). Foliar spray applications of 160 $mg \cdot L^{-1}$ paclobutrazol or 45 $mg \cdot L^{-1}$ uniconazole suppressed height in *Tradescantia virginiana* L. cultivars (White et al., 2005). Gibson and Whipker (2001a) studied ornamental cabbage and kale cultivars and found that spraying 2,500 $mg \cdot L^{-1}$ daminozide twice produced better growth control and resulted in plants that were 21% shorter than untreated plants.

Plant growth regulators may also be applied as substrate drenches to final containers or as liner soaks for effective growth control of floriculture crops. Schnelle and Barrett (2010) found that applying paclobutrazol as a soak to three different bedding plant liners resulted in decreased size when compared to the control. Paclobutrazol applied as a drench to Rhododendron (*Rhododendron catawbiense* Michx.) was more effective at inhibiting growth when applied in the liner stage before transplant rather than after transplant (Gent, 2004).

The objective of this study is to evaluate the effects of foliar and liner soak applications of various plant growth regulators on reducing growth in two *Penstemon x mexicali* cultivars, Pike's Peak Purple and Red Rocks.

Materials and Methods

PGR Screening on *Penstemon x mexicali* 'Pike's Peak Purple'

Unrooted cuttings of *Penstemon x mexicali* 'Pike's Peak Purple' were obtained from Aris Horticulture Inc. The cuttings were stuck in 72 size flats (height 5.71 cm, volume 35.4 ml) filled with a peat-based soilless substrate (Fafard 1P, Sun Gro Horticulture Canada Ltd., Agawam, MA) on December 4, 2013. The lower 2 cm of the cuttings were dipped in 1,000 $mg \cdot L^{-1}$ IBA rooting hormone solution (indole-3-butyric acid, Hortus IBA Water Soluble Salts 20% IBA, Hortus USA Corp, New York, NY) for 3 seconds prior to sticking. The cuttings were allowed to root under mist in a glass greenhouse for 2 weeks. While under mist, the cuttings were irrigated without fertilizer. After the cuttings were rooted, they received 13N-0.9P-10.8K (Peter's Plug and Bedding Plant Special, The Scotts Co. LLC, Marysville, OH) at 100 $mg \cdot L^{-1}$ N via constant liquid feed (CLF). The liners were then transplanted into quart-sized pots (1.13 L) containing a peat based soilless substrate (Fafard 3B, Sun Gro Horticulture Canada Ltd.) media and received 150 $mg \cdot L^{-1}$ N of 15N-2.2P-12.5K-4Ca-2Mg (Jack's Professional, J.R. Peters Inc., Allentown, PA) via CLF for the remainder of their production. After transplant, the potted plants were grown and finished in a gothic-arch style greenhouse with a double layer covering of polyethylene. The temperature of the greenhouse averaged at 19.7°C with a daily light integral (DLI) of 10.5 $mol·m^{-2}·d^{-1}$. In addition to natural lighting, HPS supplemental lights were set for 16 hour, long days.

Three different PGRs were tested. PGR applications to 'Pike's Peak Purple' included an untreated control, foliar spray applications of 80 or 160 $mg·L^{-1}$ paclobutrazol (Piccolo10 XC, 4.0%; Fine Americas, Inc., Walnut Creek, CA), 16 $mg·L^{-1}$ liner drench or liner soak applications of paclobutrazol, 30 or 45 $mg·L^{-1}$ foliar spray applications of uniconazole (Concise, 0.055%; Fine Americas, Inc.), or two foliar applications of 5000 $mg·L^{-1}$ daminozide (Dazide, 85%; Fine Americas, Inc.). The second daminozide treatment was applied about two weeks after the first treatment. PGRs were applied as either liner drenches or soaks before transplant, or as a foliar spray at a volume of 210 $ml·m^2$ after transplant. The liner drench was applied by pouring 10 mL of the PGR solution over the media in each cell. Cell packs treated with the liner soak were placed in a tray filled with PGR solution for two minutes. The paclobutrazol liner drench and liner soak plants were treated one day before transplant, and the foliar application of the other PGRs occurred one week after transplant. 'Pike's Peak Purple' plants were arranged in a completely randomized design with eight single plant replications per PGR group.

Data were collected at 1, 3, 5, and 7 weeks after potting (WAP) for 'Pike's Peak Purple'. Plants were measured for plant height (from rim of the pot to the top of the plant) and plant width (average of the largest width and the width perpendicular to the largest width). Vegetative and flower stalk heights were measured at the 6 week data collection. On flowering plants, the vegetative height was measured from the rim of the pot to the last vegetative leaves on the plant, and the flower stalk height was measured from the rim of the pot to the top of the flowers. Days to open flower were recorded for the 'Pike's Peak Purple' plants from the day of transplant into the final container to the day of first open flower. Percent of plants flowering was measured at the 6 week data collection. Data were analyzed using Analysis of Variance ($P \leq 0.05$, Student's *t*-test) and least significant difference means separation through JMP Pro 10 (SAS Institute Inc, Cary, NC).

Paclobutrazol drench applications on *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple'

Unrooted cuttings of *Penstemon* 'Red Rocks' and 'Pike's Peak Purple' were obtained and stuck as liners on October 22, 2014 as described for the previous experiment. Once rooted, the liners received 150 $mg \cdot L^{-1}$ N of 15N-2.2P-12.5K-4Ca-2Mg (Jack's Professional, J.R. Peters Inc.) via CLF for the remainder of their production. The liners were transplanted into trade gallon pots (2.8 L) containing peat-based soilless substrate (Fafard 3B, Sun Gro Horticulture Canada Ltd.). After transplant, the potted plants were grown and finished in a gothic-arch style green-house with a double layer covering of polyethylene. The temperature of the greenhouse aver-aged at 19.3°C with a daily light integral (DLI) of 7.8 $mol \cdot m^{-2} \cdot d^{-1}$ for the growth period of 'Red Rocks' and averaged at 19.2°C with a daily light integral (DLI) of 8.4 $mol \cdot m^{-2} \cdot d^{-1}$ for the growth period of 'Pike's Peak Purple.' In addition to natural lighting, HPS supplemental lights were set for 16 hour, long days.

Four PGR drench rates were applied to each *Penstemon* cultivar. PGRs were applied during the liner stage before transplant as a drench by pouring 10 mL of the PGR solution over the media in each cell. The PGR rates included an untreated control and paclobutrazol drenches at either 4, 8, or 12 $mg \cdot L^{-1}$. Each *Penstemon* cultivar was set up as an individual experiment with plants arranged in a completely randomized design with six single plant replications per PGR rate.

Data were collected at 0, 2, 4, 6, and 8 weeks after potting (WAP) for 'Pike's Peak Purple' and 'Red Rocks'. Plants were measured for plant height and plant width as described above at all data collections. Days to open flower were recorded for both the 'Pike's Peak Purple' and 'Red Rocks' plants from the day of transplant into the final container to the day of first open flower. Data were analyzed using Linear Regression and Analysis of Variance ($P \leq 0.05$, Student's *t* test) through JMP Pro 10 (SAS Institute Inc, Cary, NC).

Results (See Appendix for complete data tables)

PGR Screening on *Penstemon x mexicali* 'Pike's Peak Purple'

At the time of the first data collection (1 WAP) before foliar PGR applications, there was a significant difference between the plants subjected to the pre-transplant paclobutrazol liner drench or liner soak and those in the control group (Table 3.1). Both the paclobutrazol liner soak and liner drench significantly reduced plant height (29% and 36%, respectively) as compared to plants in the control and not yet treated groups (Figure 3.1).

At 3 weeks after potting, the plants subjected to the foliar PGR applications were shorter when compared to the control group (Table 3.1, Figure 3.2). The 80 $mg \cdot L^{-1}$ paclobutrazol foliar application resulted in a 21% reduction in height, and the 160 $mg \cdot L^{-1}$ paclobutrazol foliar application resulted in a 37% reduction in height. The 30 $mg \cdot L^{-1}$ uniconazole foliar application resulted in a 17% height reduction, and the 45 $mg \cdot L^{-1}$ uniconazole foliar application resulted in a 27% height reduction. The daminozide foliar application did not affect plant height as compared to the control. The plants subjected to the paclobutrazol liner soak or liner drench were stunted, 56% or 63%, respectively, shorter when compared to plants in the control group. Average plant width was not significantly reduced in any of the foliar PGR applications as compared to the control. The average width was reduced in both of the liner applications with a 20% reduction in the liner soak group and a 21% reduction in the liner drench group as compared to the control group.

At 5 WAP, the plants subjected to the foliar applications displayed reduced plant height (Table 3.1, Figure 3.2). The 80 mg·L^{-1} paclobutrazol foliar application resulted in a 26% reduction in height, and the 160 mg·L^{-1} paclobutrazol foliar application resulted in a 46% reduction in height. The 30 mg·L^{-1} uniconazole application resulted in a 20% height reduction, and the 45 mg·L^{-1} uniconazole application resulted in a 30% height reduction. The daminozide foliar application resulted in a 14% height reduction as compared to the control. The plants subjected to the paclobutrazol liner soak or drench were 62% or 68%, respectively, shorter plants than the control. Average width was not significantly different in the foliar paclobutrazol or uniconazole PGR applications as compared to the control. The daminozide application resulted in an increased average width of 12% as compared to the control group. Average width was reduced by 16% in the liner soak and by 21% in the liner drench.

At the final data collection (7 WAP), vegetative height reductions persisted with the 80 or 160 mg·L^{-1} paclobutrazol foliar applications, or with 30 or 45 mg·L^{-1} uniconazole applications, as compared to the control (Table 3.2, Figure 3.3). The daminozide application group had no persistent effect on plant height when compared to the control. Plants subjected to the liner soak were still 44% shorter than control plants, and plants subjected to the liner drench had the most reduced growth when compared to the control plants with a 54% reduction in plant height (Table 3.2). Flower stalk height was reduced 20% by the 80 mg·L^{-1} paclobutrazol application, 36% by 160 mg·L^{-1} paclobutrazol, 13% by 30 mg·L^{-1} uniconazole, 20% by 45 mg·L^{-1} uniconzole, and not affected by daminozide as compared to the control plants. Flower stalk height was stunted with the liner applications; 56% in the paclobutrazol liner soak and 62% in the liner drench when compared to the control group. Average width was reduced 22% by 80 mg·L⁻¹ paclobutrazol group, 36% by 160 mg·L⁻¹ paclobutrazol, 19% by 30 mg·L⁻¹ uniconazole, or 27% by 45 mg·L⁻¹ uniconzole, and 11% by daminozide as compared to the control plants. The greatest reduction in average plant width was seen in the plants subjected to the liner soak at 39% and the liner drench at 54%. There was no significant difference in the number of days required to flower between the PGR applications. However, there were low flowering percentages seen in four of the PGR applications. The percent of plants flowering varied with the PGR application with 25% in the 160 mg·L⁻¹ paclobutrazol spray group, 38% in the daminozide group, 25% in the paclobutrazol drench group, and none flowering in the paclobutrazol liner soak. These low flowering percentages were most likely due to stunting as a result of these PGR applications.

Paclobutrazol drench applications on *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple'

'Red Rocks' Data was taken 1 day prior to potting to confirm uniformity of the liners (Figure 3.4). There was no significant difference in the initial height or width at the time of potting (data not presented). At 2 weeks after potting (WAP), all paclobutrazol-drenched plants were significantly smaller than the control plants in both height and average width (Table 3.3, Figure 3.5). Height was reduced by 42% with the 4 mg·L⁻¹ rate, 44% with the 8 mg·L⁻¹ rate, and 52% with the 12 mg·L⁻¹ rate. Both height and width showed a significant linear and quadratic response to increasing rate.

At 4 weeks after potting, the 4 mg·L⁻¹ paclobutrazol drench reduced height by 50% when compared to the control group (Table 3.3, Figure 3.5). The 8 or 12 mg·L⁻¹ paclobutrazol drenches had the greatest amount of height reduction at 58% and 63% compared to the control, which resulted in stunting (Figure 3.6). Average width was significantly reduced in all of the paclobutrazol groups from 43% in the 4 mg·L^{-1} group, to 45% in the 8 mg·L^{-1} group, and 43% in the 12 mg·L^{-1} group. Both plant height and average width had significant linear and quadratic responses to paclobutrazol rates. However, the quadratic regression was a better fit for both height (R^2 = 0.91) and average width (R^2 = 0.87) than the linear regression. In the quadratic regression, height was decreased as paclobutrazol rate increased until the PGR appeared to reach saturation point at the 8 mg·L^{-1} rate with little additional reduction in height as the rate continued to increase. Average width was significantly decreased with the application of the 4 mg·L^{-1} paclobutrazol drench but did not respond further as the rate increased.

By 6 weeks after potting, 4 mg·L^{-1} paclobutrazol reduced height 53%, and 8 mg·L^{-1} paclobutrazol reduced height 61% when compared to the untreated control plants (Table 3.4, Figure 3.7). The 12 mg·L^{-1} paclobutrazol drench caused stunting and the greatest height reduction at 69% when compared to the controls (Figure 3.6). Average width was decreased significantly with all paclobutrazol rates compared to the control plants. There was a reduction in average width by 50% in the 4 mg·L^{-1} group, 56% in the 8 mg·L^{-1} group, and 55% in the 12 mg·L^{-1} group. Both the linear and quadratic regressions were significant for both plant height and average width, but the quadratic regression continued to have a higher R^2 value and therefore a better fit than the linear regression. Plant height was decreased as the paclobutrazol rate increased, and average width decreased with the application of the paclobutrazol, but growth did not decrease further as the rate increased. Plants were stunted by the lowest drench rate, 4 mg·L^{-1} paclobutrazol.

By the final data collection (8 WAP), height was reduced 57% by the 4 mg·L^{-1} paclobutrazol rate, 67% by the 8 mg·L^{-1} rate, and 66% by the 12 mg·L^{-1} rate when compared to the control (Table 3.4, Figure 3.7). The paclobutrazol 4 mg·L^{-1} group had reduced average width when compared to the control at 55%. Average width was significantly reduced in the 8 and 12 mg·L^{-1} paclobutrazol groups at 70 and 71%, respectively. Both the linear and quadratic regressions were significant for plant height and plant width, but the quadratic regression was a better fit than the linear regression. Height and width were decreased as the paclobutrazol rate increased until the PGR reached saturation point and where growth no longer responded as rate increased. All plants were stunted by all rates. All drenched plants flowered by the end of the experiment, and days to flower were observed. The paclobutrazol 8 and 12 mg·L^{-1} groups took significantly longer to flower than the control group. Both the linear and quadratic regressions were significant, but neither regressions were a good fit for days to flower.

'Pike's Peak Purple' Data was taken 1 day prior to potting to confirm uniformity (data not presented). There was no significant difference in the initial height or width at the time of potting (Figure 3.8). At 2 weeks after potting (WAP), height was reduced by all three paclobutrazol rates, 48% by the 4 mg·L^{-1} rate, 46% by the 8 mg·L^{-1} rate, and 55% by the 12 mg·L^{-1} rate when compared to the control plants (Table 3.5, Figure 3.9). Average width was reduced 14% by the 4 mg·L^{-1} paclobutrazol drench, 10% by the 8 mg·L^{-1} paclobutrazol drench, and 19% by the 12 mg·L^{-1} paclobutrazol drench. A significant linear and quadratic response occurred for both plant height and width.

By 4 weeks after potting, the 4 mg·L^{-1} paclobutrazol drench reduced height 58%, and the 8 mg·L^{-1} paclobutrazol drench reduced height 60%. Height was significantly reduced 70% by the 12 mg·L^{-1} drench when compared to the control. Average width was significantly reduced 37%

by both the 4 and 8 $mg \cdot L^{-1}$ drenches, and 47% by the 12 $mg \cdot L^{-1}$ drench (Table 3.5, Figure 3.9). Both the linear and quadratic regressions were significant for plant height and plant width, and the quadratic regression was a better fit than the linear regression. Both height and width were decreased as the paclobutrazol rate increased until the PGR reached saturation point and growth could not respond further.

At 6 weeks after potting, the 4 $mg \cdot L^{-1}$ drench reduced height 49% and the 8 $mg \cdot L^{-1}$ drench reduced height 54% (Table 3.6, Figure 3.10). The highest paclobutrazol rate caused the greatest height reduction at 69%. Average width was reduced at 45% and 48%, respectively, by the 4 and 8 $mg \cdot L^{-1}$ paclobutrazol drenches when compared to the control plants. The 12 $mg \cdot L^{-1}$ paclobutrazol drench reduced average width by 60% when compared to the control group. Both the linear and quadratic regressions were significant as plant height and average width decreased with increasing paclobutrazol rates, but the quadratic regression continued to have a higher R^2 value and therefore was a better fit than the linear regression.

At the final data collection (8 WAP), height was reduced 32% by the 4 $mg \cdot L^{-1}$ drench and 40% by the 8 $mg \cdot L^{-1}$ drench (Table 3.6, Figure 3.10). The 12 $mg \cdot L^{-1}$ drench had a significant reduction in height at 56%. Average width was reduced 46% by the 4 $mg \cdot L^{-1}$ drench, 56% by the 8 $mg \cdot L^{-1}$ drench, and 66% by the 12 $mg \cdot L^{-1}$ drench as compared to the control. Both the linear and quadratic regressions were significant for plant height and width, but the quadratic regression was a better fit than the linear regression. Both height and average width were decreased as the paclobutrazol rate increased. Days to flower had both significant linear and quadratic responses. The highest paclobutrazol rate was the only one to cause a significant delay in flowering and bloomed 5 days later than the control plants.

Discussion

PGR Screening on *Penstemon x mexicali* 'Pike's Peak Purple'

It is clear that the paclobutrazol liner drench or liner soak were the most effective treatments at growth reduction. Blanchard and Runkle (2007) reported that applying liner dips/soaks of paclobutrazol at 4, 8, or 16 $mg \cdot L^{-1}$ to different bedding plants resulted in reduced stem elongation and shorter plants. Paclobutrazol drenches were also effective at controlling growth in various potted floriculture crops (Barrett et al., 1994). However, the plants resulting from these applications were over-regulated and not marketable due to severe stunting. Further experiments will determine which liner soak or drench concentrations of paclobutrazol would be best for optimum growth regulation of this crop, but it is clear that a paclobutrazol liner soak or drench concentration below 16 $mg \cdot L^{-1}$ is needed for use on this particular Penstemon. In contrast, the foliar spray applications of paclobutrazol, uniconazole, and daminozide did not visibly reduce height and width enough for desirable growth control. However, Starman (1990) found that foliar applications of uniconazole and daminozide were effective at reducing height in chrysanthemums (*Denranthema x grandiflorurn, Chrysanthemum x morifolium* Ramat.). In addition, Gibson and Whipker (2001b) found that using a foliar application of daminozide at 5000 $mg \cdot L^{-1}$ was effective at producing shorter ornamental kale and cabbage cultivars (*Brassica oleracea* var. acephala). Higher concentrations or multiple applications of these sprays may be needed in order to provide a sufficient growth regulation to create a marketable plant.

Paclobutrazol drench applications on *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple'

All three concentrations of the paclobutrazol drench reduced height and average width in both of the *Penstemon* cultivars. Over-regulation and stunting was evident in these treatment groups as well, especially with the higher paclobutrazol concentrations. In a study by Ruter (1996), drench applications of paclobutrazol were effective at reducing growth in ‘New Gold’ lantana (*Lantana camara* L.), but lower rates were recommended as a result of too much growth control. The results of this study suggest that future drench rates should be reduced further in order to prevent over-regulation and stunting of the plants. Whipker and Hammer (1997) found that 2 to 4 mg or 4 to 8 mg of a paclobutrazol drench application produced marketable dahlia (*Dahlia variabilis* Willd.) plants depending on the cultivar.

The paclobutrazol drench also produced darker green and glossy foliage in ‘Red Rocks’ but not in ‘Pike’s Peak Purple.’ In a study by Mansuroglu et al. (2009), foliar applications of paclobutrazol produced darker green foliage in the plant *Consolida orientalis* (Gay) Schröd. In ‘Red Rocks’, flowering was delayed by the two higher paclobutrazol rates, whereas a delay in flowering was only seen in the highest paclobutrazol rate in ‘Pike’s Peak Purple.’ Delays in flowering were seen in bleeding heart (*Dicentra spectabilis* (L.) Lem.) as a result of different PGR applications (Kim et al., 1999). It is clearly evident that liner drenches of paclobutrazol are effective at reducing growth in *Penstemon* cultivars. However, it is critical that preliminary tests be performed before application of this PGR on *Penstemon* in order to find the ideal concentration that reduces growth but does not cause over-regulation to the crop.

Literature Cited

Barret, J.E. and T.A. Nell. 1992. Efficacy of paclobutrazol and uniconazole on four bedding plant species. HortScience 27(8):896-897.

Barret, J.E., C.A. Bartuska, and T.A. Nell. 1994. Comparison of paclobutrazol drench and spike applications for height control of potted floriculture crops. HortScience 29(3): 1994.

Blanchard, M.G. and E.S. Runkle. 2007. Dipping bedding plant liners in paclobutrazol or uniconazole inhibits subsequent stem extension. HortTechnology 17(2): 178-182.

Gent, M.P.N. 2004. Efficacy and persistence of paclobutrazol applied to rooted cuttings of rhododendron before transplant. HortScience 39(1):105-109.

Gibson, J.L. and B.E. Whipker. 2001a. Ornamental cabbage and kale growth responses to daminozide, paclobutrazol, and uniconazole. HortTechnology 11(2):226-230.

Gibson, J.L. and B.E. Whipker. 2001b. Ornamental cabbage and kale cultivar comparison study: growth characteristics and response to daminozide and uniconazole foliar sprays. HortTechnology 11(3): 376-380.

Kessler, Jr, J.R. and G.J. Keever. 2008. Plant growth retardants affect growth and flowering of *Achillea* x 'Coronation Gold.' J. Environ. Hort. 26(1):24-28.

Kim, S.H., A.A. De Hertogh, and P.V. Nelson. 1999. Effects of plant growth regulators applied as sprays or media drenches on forcing of Dutch-grown bleeding heart as a flowering potted plant. HortTechnology 9(4):630-635.

Latmer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Ann. Conf. Plant Growth Regulator Society Amer. 31:1-4.

Mansuroglu, S., O. Karaguzel, V. Ortacesme, and M. Selcuksayan. 2009. Effect of paclobutrazol on flowering, leaf and flower colour of *Consolida orientalis*. Pak. J. Bot. 41(5): 2323-2332.

Ruter, J.M. 1996. Paclobutrazol application method influences growth and flowering of 'New Gold' Lantana. HortTechnology 6(1): 19-20.

Schnelle, R.A. and J.E. Barrett. 2010. Paclobutrazol concentration and substrate moisture status impact efficacy of liner dips for size control of three bedding plants. HortTechnology 20(4):735-739.

Starman, T.W. 1990. Whole-plant response of chrysanthemum to uniconazole foliar sprays or medium drenches. HortScience 25(8): 935-937.

Whipker, B.E. and P.A. Hammer. 1997. Efficacy of ancymidol, paclobutrazol, and uniconazole on growth of tuberous-rooted dahilias. HortTechnology 7(3): 269-273.

White, S.A., H.L. Scoggins, R.P. Marini, and J.G. Latimer. 2005. Multivariate repeated measures analysis of plant growth regulators on Tradescantia virginiana. HortScience 40(2):404-408.

Table 3.1. Plant height and average width of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at 1 week, 3 weeks, and 5 weeks after potting (WAP). Paclobutrazol liner soaks and drenches were applied 1 day prior to potting, and foliar applications of the PGRs paclobutrazol, uniconazole, and daminozide were applied one week after potting.

	1 week	3 weeks		5 weeks	
PGR ($mg \cdot L^{-1}$)	Plant height (cm)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)
Control	10.9ab[z]	19.9a	12.1ab	29.8a	12.6b
80 Paclobutrazol spray	10.9ab	15.8bc	11.4ab	22.1bc	12.4b
160 Paclobutrazol spray	9.8b	12.6d	11.3b	16.1d	12.0b
30 Uniconazole spray	11.9a	16.6bc	12.1ab	23.9bc	12.5b
45 Uniconazole spray	11.1ab	14.6cd	11.3ab	20.9c	12.1b
5000 Daminozide spray	10.3ab	17.8ab	12.2a	25.6b	14.1a
16 Paclobutrazol liner drench	7.0c	7.4e	9.5c	9.6e	10.0c
16 Paclobutrazol liner soak	7.7c	8.7e	9.7c	11.3e	10.6c
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD	1.7	2.4	0.9	3.7	1.2

[z]Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).

Table 3.2. Vegetative height, flower stalk height, average width, days to flower, and percent of plants flowering of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at 7 weeks after potting and application of paclobutrazol liner soak and drenches and 6 weeks after foliar application of the PGRs paclobutrazol, uniconazole, and daminozide.

PGR ($mg·L^{-1}$)	Vegetative height (cm)	Flower stalk height (cm)	Plant width (cm)	Days to Flower[x]	Percent (%) Plants flowering
Control	23.7a[z]	42.4a	16.8a	38	63%
80 Paclobutrazol spray	20.0b	34.0c	13.1cd	38	63%
160 Paclobutrazol spray	17.4c	27.0d	10.7ef	45	25%
30 Uniconazole spray	18.9bc	36.9bc	13.7bc	41	100%
45 Uniconazole spray	18.8bc	33.8c	12.2de	42	88%
5000 Daminozide spray	24.2a	38.4ab	14.9b	35	38%
16 Paclobutrazol liner drench	10.8e	16.3e	7.8g	47	25%
16 Paclobutrazol liner soak	13.3d	18.5e	10.3f	--	0%
P-value	<0.0001	<0.0001	<0.0001	0.3147	<0.0001
LSD	2.5	--[y]	1.5	--	--

[z]Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).
[y]LSD not available for flowering data due to not all plants flowering in the PGR groups.
[x]Days to flower were measured from the day of transplant to the day of first open flower.

Table 3.3. Plant height and average width of *Penstemon x mexicali* 'Red Rocks' at 2 and 4 weeks after potting (WAP). Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

	2 weeks		4 weeks	
Paclobutrazol rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)
0	8.0	12.8	12.2	14.5
4	4.7	9.3	6.2	8.3
8	4.5	9.5	5.2	7.9
12	3.8	10.0	4.5	8.3
Linear	<0.0001	0.0029	<0.0001	<0.0001
R^2	0.536	0.307	0.7265	0.5206
Quadratic	<0.0001	<0.0001	<0.0001	<0.0001
R^2	0.649	0.727	0.9133	0.869

Table 3.4. Plant height and average width of *Penstemon x mexicali* 'Red Rocks' at 6 and 8 weeks after potting (WAP). Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

	6 weeks		8 weeks		
Paclobutrazol rate ($mg·L^{-1}$)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)	Days to flower[z]
0	22.2	19.6	30.8	29.4	46
4	10.5	9.8	13.2	13.1	48
8	8.7	8.7	10.3	8.8	49
12	6.8	8.9	10.5	8.7	50
Linear	<0.0001	<0.0001	<0.0001	<0.0001	0.0005
R^2	0.739	0.602	0.580	0.704	0.405
Quadratic	<0.0001	<0.0001	<0.0001	<0.0001	0.0026
R^2	0.900	0.8994	0.816	0.924	0.379

[z]Days to flower were measured from the day of transplant to the day of first open flower.

Table 3.5. Plant height and average width of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at the time of potting and at 2 and 4 weeks after potting (WAP). Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

	2 weeks		4 weeks	
Paclobutrazol rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)
0	11.8	12.3	20.2	17.4
4	6.2	10.6	8.5	10.9
8	6.3	11.1	8.0	10.9
12	5.3	10.0	6.2	9.3
Linear	<0.0001	0.0004	<0.0001	<0.0001
R^2	0.599	0.413	0.703	0.704
Quadratic	<0.0001	0.0016	<0.0001	<0.0001
R^2	0.777	0.406	0.899	0.843

Table 3.6. Plant height and average width of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at 6 and 8 weeks after potting (WAP). Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

	6 weeks		8 weeks		
Paclobutrazol rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)	Days to flower[z]
0	29.7	23.6	51.5	34.6	52
4	15.3	12.9	35.0	18.8	52
8	13.7	12.3	30.8	15.4	51
12	9.2	9.5	22.8	11.7	57
Linear	<0.0001	<0.0001	<0.0001	<0.0001	0.0044
R^2	0.779	0.757	0.897	0.789	0.283
Quadratic	<0.0001	<0.0001	<0.0001	<0.0001	0.0005
R^2	0.874	0.886	0.936	0.903	0.467

[z]Days to flower were measured from the day of transplant to the day of first open flower.

Figure 3.1. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants 1 week after potting (1 WAP) and 1 week after 16 mg·L^{-1} paclobutrazol (PAC) was applied as a liner soak (soak) at 2 minutes in solution or as a liner drench (dr) at 10 mL per pot, at the time of application of foliar PGR treatments.

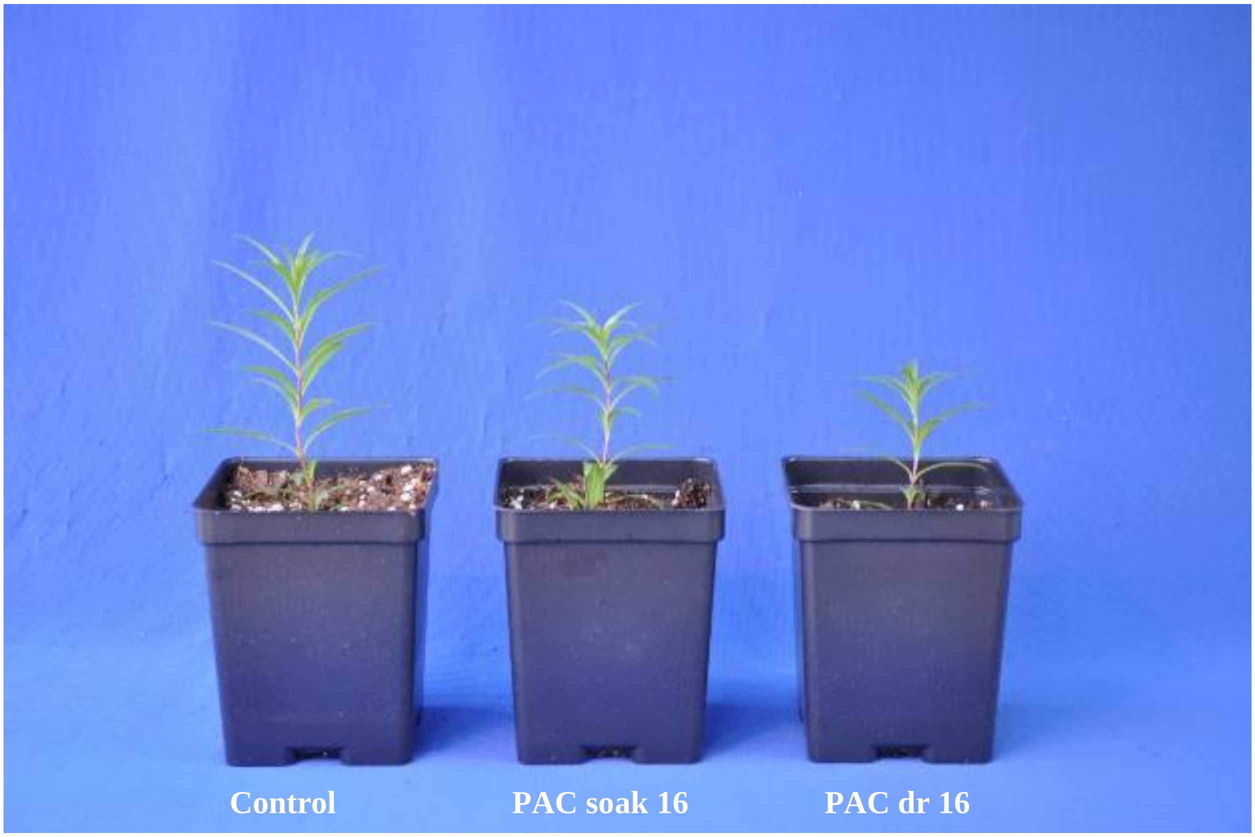


Figure 3.2. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 3 weeks (top photo) and 5 weeks (bottom photo) after potting (left to right): untreated control, 16 $mg \cdot L^{-1}$ paclobutrazol liner soak (PAC soak 16), 16 $mg \cdot L^{-1}$ paclobutrazol liner drench (PAC dr. 16), 80 $mg \cdot L^{-1}$ paclobutrazol foliar spray (PAC sp. 80), 160 $mg \cdot L^{-1}$ paclobutrazol foliar spray (PAC sp. 160), 30 $mg \cdot L^{-1}$ uniconazole foliar spray (UNI sp. 30), 45 $mg \cdot L^{-1}$ uniconazole foliar spray (UNI sp. 45), and 5000 $mg \cdot L^{-1}$ daminozide foliar spray (DAM 5000).

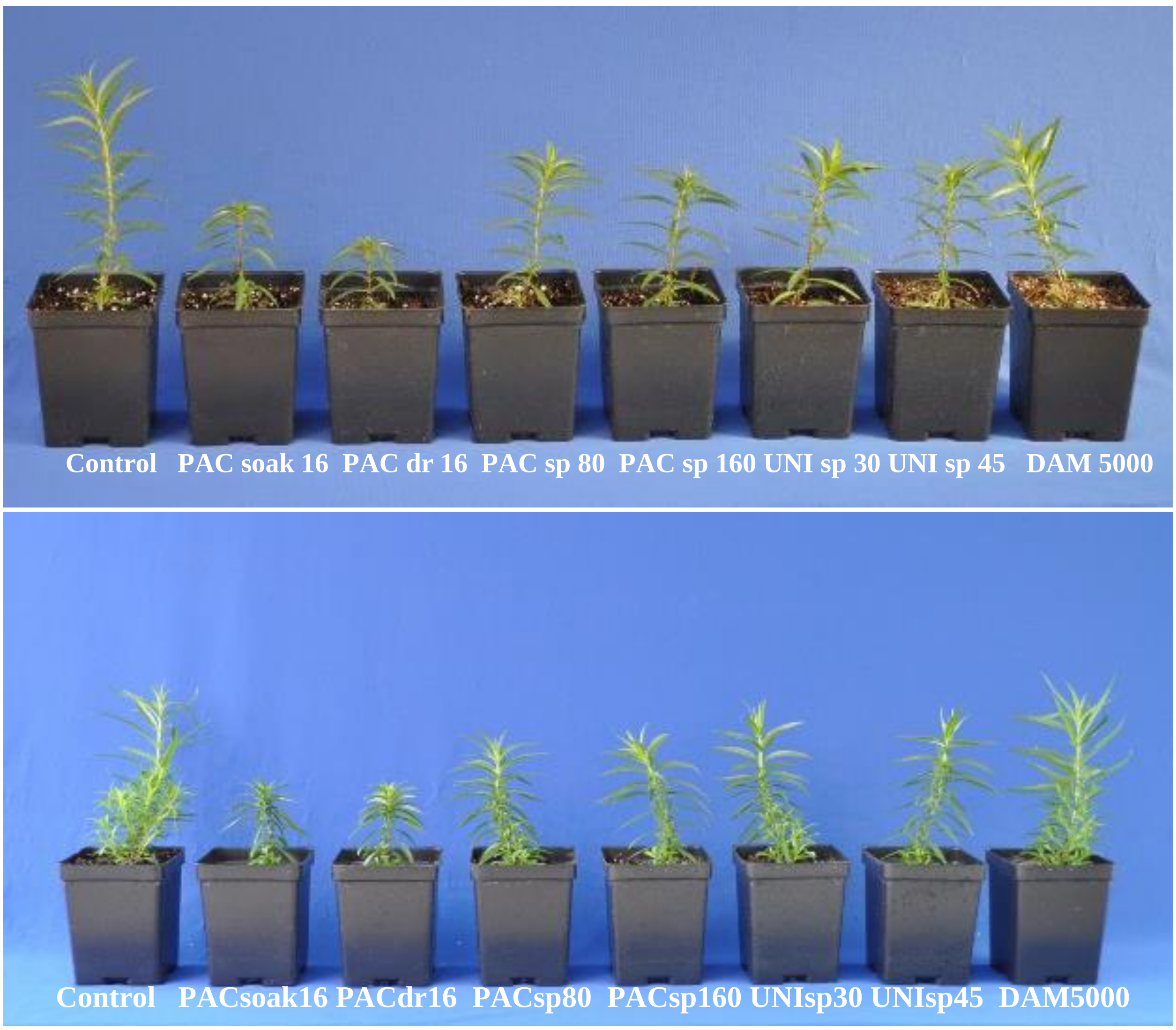


Figure 3.3. *Penstemon x mexicali* 'Pike's Peak Purple' plants at 7 weeks after potting (left to right): untreated control, 16 mg·L^{-1} paclobutrazol liner soak (PAC soak 16), 16 mg·L^{-1} paclobutrazol liner drench (PAC dr. 16), 80 mg·L^{-1} paclobutrazol foliar spray (PAC sp. 80), 160 mg·L^{-1} paclobutrazol foliar spray (PAC sp. 160), 30 mg·L^{-1} uniconazole foliar spray (UNI sp. 30), 45 mg·L^{-1} uniconazole foliar spray (UNI sp. 45), and 5000 mg·L^{-1} daminozide foliar spray (DAM 5000).

Figure 3.4. *Penstemon x mexicali* ‘Red Rocks’ plant liners at the time of application of paclobutrazol (PAC) drenches.

Figure 3.5. *Penstemon x mexicali* ‘Red Rocks’ plants at 2 weeks (top photo) and 4 weeks (bottom photo) after application of paclobutrazol (PAC) liner drenches at 0, 4, 8 or 12 $mg{\cdot}L^{-1}$ and potting (WAP).

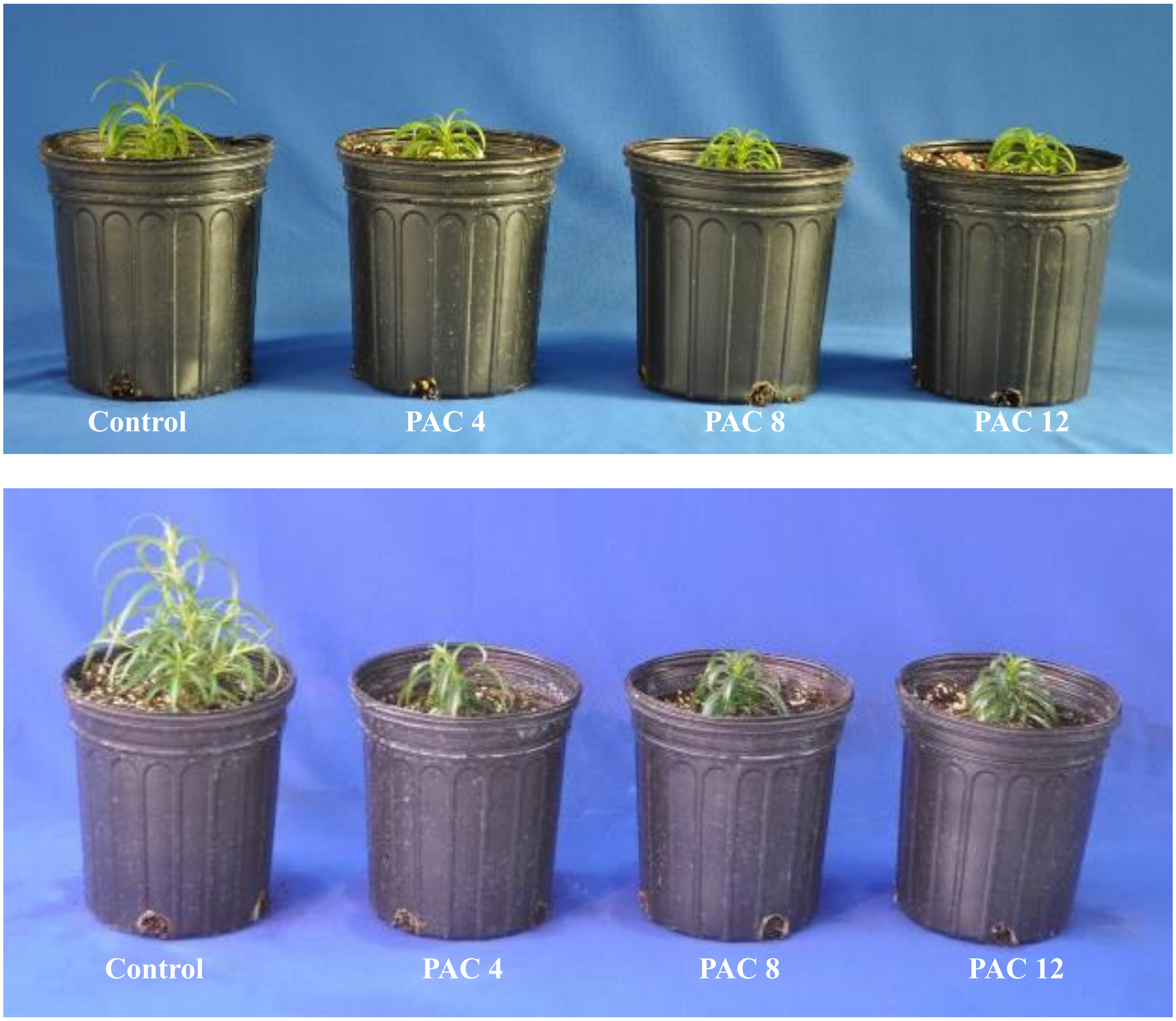


Figure 3.6. *Penstemon x mexicali* ‘Red Rocks’ stunting at 4 weeks (left) and 6 weeks (right) after potting and application of 12 mg$\cdot$L^{-1}paclobutrazol (PAC) liner drench.

Figure 3.7. *Penstemon x mexicali* 'Red Rocks' plants at 6 weeks (top photo) and 8 weeks (bottom photo) after potting and application of paclobutrazol (PAC) liner drenches at 0, 4, 8 or 12 mg·L^{-1}.

Figure 3.8. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plant liners at the time of application of paclobutrazol (PAC) drenches.

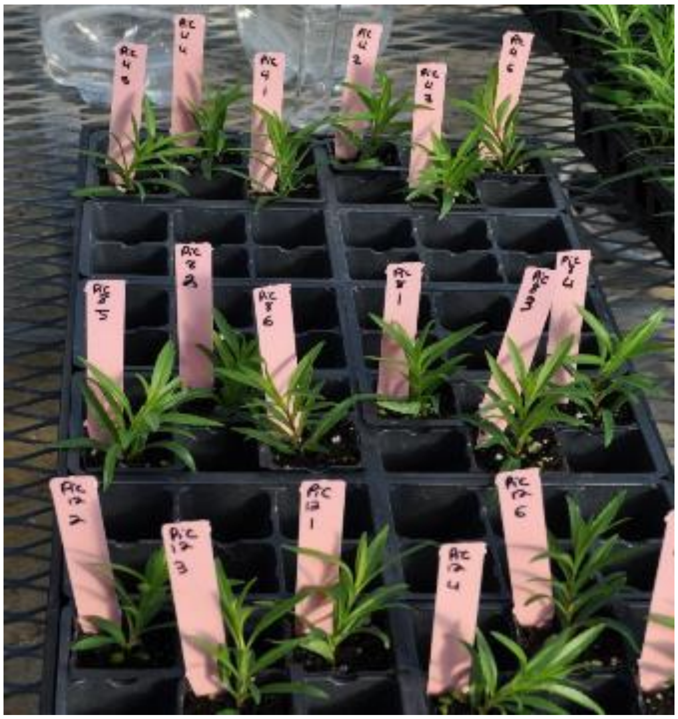


Figure 3.9. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 2 weeks (top photo) and 4 weeks (bottom photo) after application of paclobutrazol (PAC) liner drenches at 0, 4, 8 or 12 $mg \cdot L^{-1}$ and potting (WAP).

Figure 3.10. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 6 weeks (top photo) and 8 weeks (bottom photo) after potting and application of paclobutrazol (PAC) liner drenches at 0, 4, 8 or 12 mg·L^{-1}.

Appendix B

Appendix

Table B.1. Plant height and average width of *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple' at the time of potting (0 WAP) and 1 day after the application of paclobutrazol liner drenches.

	Red Rocks		Pike's Peak Purple	
Paclobutrazol rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Plant height (cm)	Plant width (cm)
0	4.7	9.8	6.2	6.8
4	4.3	9.1	6.3	6.8
8	4.5	9.6	6.0	6.9
12	4.2	9.6	5.8	6.7
Linear	0.3906	0.8707	0.3578	0.7723
R^2	-0.010	-0.044	-0.005	-0.040
Quadratic	0.6978	0.5424	0.5797	0.8915
R^2	-0.050	-0.033	-0.039	-0.080
LSD	1.0	1.0	1.0	1.0

Chapter 4: Evaluation of PGR Growth Retardants and Branching Agents on *Penstemon x mexicali* 'Red Rocks' and 'Pike's Peak Purple'

Introduction

Plant growth regulators are chemicals often applied to crops in the greenhouse and nursery industries for the purposes of height control and regulating growth (Pilon, 2006). These plant growth regulators may be used as an alternative method to replace manual techniques like pinching and pruning for growers. Traditional methods such as pinching and pruning are used to control the growth of crops in the greenhouse and nursery industries (Cochran et al., 2013). Pinching is beneficial for growth control of crops because it helps to break apical dominance and promote lateral bud growth to increase branching (Starman, 1991). Although pinching enhances the aesthetic quality and regulates growth of containerized crops, it is labor-intensive and not cost-effective for growers, especially if multiple applications are required for the same crop (Richards and Wilkinson, 1984). Plant growth regulators offer growers the possibilities of not only reducing labor and costs but also producing high quality and marketable plants that can be sold in the industry.

Plant growth regulators known as plant growth retardants or Anti-GAs control height by inhibiting the production of gibberellins, which prevents shoot and stem elongation from occurring (Dole and Wilkins, 2005). In the industry, there are many PGR products that function by inhibiting different steps of the biosynthesis pathway (Pilon, 2006). Growers often use two PGRs together with each affecting a different step of the gibberellin pathway to ensure the effectiveness of growth control; this combination of PGRs is called a tank mix (Pilon, 2006). Growth retardants are applied to crops various ways depending on how active or inactive the PGR is in the soil, and if it is absorbed through the roots, stems, or leaves (Latimer, 2004). Paclobutrazol, a commonly used PGR in the floriculture industry, can be applied as foliar and drench applications. Both foliar and drench applications of paclobutrazol were effective at reducing height in

Dianthus caryophyllus L. ‘Mondriaan’ (Bañón et al., 2002). Because paclobutrazol is soil-active, it may be more effective at reducing growth by applying it to crops as a drench or liner soak. Gibson and Whipker (2003) found substrate drench applications of paclobutrazol to be effective at regulating growth of *Osteospermum ecklonis* (DC.) Norl., whereas paclobutrazol foliar spray applications were ineffective.

In addition to regulating growth on crops, plant growth regulators can also act as branching agents and promote lateral branching in crops (Dole and Wilkins, 2005). Several branching PGRs used in the floriculture industry include benzyladenine, ethephon, and dikegulac sodium (Latimer and Freeborn, 2009). In many instances, certain floriculture crops may require application of both branching agents and gibberellin inhibiting PGRs in order to regulate and control growth while in a container.

The objective of this study is to analyze the effects pinching techniques, branching agents, and growth retardants have on regulating growth of *Penstemon x mexicali* ‘Red Rocks’ and ‘Pike’s Peak Purple.’ The goal of this study is to determine which methods or combination of PGRs are the most effective at producing salable, containerized Penstemon that can be grown in the floriculture industry.

Materials and Methods

Unrooted cuttings of *Penstemon x mexicali* ‘Red Rocks’ and ‘Pike’s Peak Purple’ were obtained from Aris Horticulture Inc and stuck in 72 size flats on October 22, 2014 as described for the previous experiments. ‘Red Rocks’ was chosen as an addition to this study because of its genetic similarities to ‘Pike’s Peak Purple.’ The goal of the study was to analyze how each cultivar responds to the same applications of pinching, growth retardants, and branching agents. The cuttings were allowed to root under mist in a glass greenhouse for two or more weeks. The liners (Figure 4.1) were transplanted into trade-gallon pots (2.8 L) containing a peat-based soilless media (Fafard 3B) media and received 150 $mg \cdot L^{-1}$ N of 15N-2.2P-12.5K-4Ca-2Mg (Jack's Professional) via CLF for the remainder of their production. After transplant, the potted plants were grown and finished at different times in two different greenhouses in order to maximize the best environmental conditions for growth. The plants were first grown in a gothic-arch style greenhouse with a double layer covering of polyethylene and then were transferred into a poly-hoop house covered with polycarbonate for several weeks. Both cultivars were then finished back in the gothic-style greenhouse for the remaining few weeks of their growth.

'Red Rocks' Greenhouse Locations (days)	Average Temperature (°C)	Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)
1st stay- Polyethylene (8)	20.4	10.9
Poly-hoop (34)	18.6	11.9
2nd stay Polyethylene (22)	19.1	10.3

'Pike's Peak Purple' Greenhouse Locations (days)	Average Temperature (°C)	Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$)
1st stay- Polyethylene (14)	19.8	12.2
Poly-hoop (42)	18	13.4
2nd stay Polyethylene (14)	25.1	8.87

In addition to natural lighting, HPS supplemental lights were set for 16 hour, long days under both greenhouse environments.

Five different PGRs were tested on 'Red Rocks' and 'Pike's Peak Purple.' The PGR applications included an untreated control, 2 (low rate) or 4 (high rate) $mg \cdot L^{-1}$ of paclobutrazol

(Piccolo10 XC, 4.0%; Fine Americas, Inc., Walnut Creek, CA) applied as a drench, 600 $mg{\cdot}L^{-1}$ dikegulac sodium foliar spray (Augeo, 18.5%; OHP, Inc., Mainland, PA), 600 $mg{\cdot}L^{-1}$ benzyladenine foliar spray (Configure, 2%; Fine Americas, Inc.), and 500 $mg{\cdot}L^{-1}$ ethephon foliar spray (Collate, 21.7%; Fine Americas, Inc.). The experiment was set up as a split plot design with 0, 2 and 4 $mg{\cdot}L^{-1}$ paclobutrazol (growth retardant) as the main plot and an untreated control and three different branching agents as the subplot. The interaction between the plots were also analyzed. All groups including the control were pinched during the liner stage to only five nodes (five sets of leaves) remaining on the plants. The three different branching agents were applied as foliar sprays at a volume of 210 $ml{\cdot}m^2$ both before and after transplant. The first foliar spray application was applied 11 days after the pinch for 'Red Rocks' and 10 days for 'Pike's Peak Purple,' once the liners had regained enough leaf area to uptake the PGRs. The second foliar treatment occurred one week after transplant. The paclobutrazol liner drench was also applied during the liner stage 18 days after pinch for 'Red Rocks' and 17 days for 'Pike's Peak Purple,' the day prior to transplant. The drench was applied by pouring 10 mL of the PGR solution over the media in each cell. 'Pike's Peak Purple' and 'Red Rocks' were set up as individual experiments with plants arranged in a split plot design with eight single plant replications per group.

Data were collected at 0, 2, 4, 6, and 9 weeks after the initial PGR foliar application (WAIT) for 'Red Rocks' and 0, 2, 4, 6, and 10 weeks after the initial PGR foliar application for 'Pike's Peak Purple.' Plants were measured for plant height, plant width, number of leaders, number of branches, number of flower stalks, and shoot dry weight (at harvest). Phytotoxicity was measured at 2 and 4 weeks after PGR application for both 'Red Rocks' (Figure 4.2) and 'Pike's Peak Purple' (Figures 4.3 and 4.4) and was rated on the following scale:

0) No damage or injury

1) Slight injury (less than 1/3 of plant affected)

2) Mild injury (1/3 of the plant affected)

3) Moderate injury (1/3 to 1/2 of plant affected)

4) Severe injury (more than 1/2 of plant affected)

5) Permanent injury and damage (entire plant is affected)

A marketability rating was assessed at 6 weeks and the final week data collections on the following scale for both 'Red Rocks' and 'Pike's Peak Purple' (Figure 4.5):

0) Death, not salable

1) Unacceptable/extremely poor quality, unsalable

2) Poor quality, unsalable

3) Okay/fair quality, some salability

4) Good quality, salable

5) Excellent/ideal quality, salable

Days to open flower were recorded for the 'Pike's Peak Purple' and 'Red Rocks' plants from the day of transplant into the final container to the day of first open flower. Data were analyzed using a split-plot design and analysis of variance ($P \leq 0.05$, Student's *t* test) through JMP Pro 10. Paclobutrazol rates were analyzed as the main plot, the branching agents applied were analyzed as the subplot, and the interaction between the main plot and subplot was also analyzed.

Results (See Appendix for complete data tables)

'Red Rocks' Plants were uniform at the time of the initial PGR application (0 WAIT, Figure 4.1). There was no significant difference in any of the variables analyzed in the main plot, subplot, and interaction between the plots (data not presented). At 2 weeks after the first PGR application, height was reduced 13% by the 2 $mg \cdot L^{-1}$ paclobutrazol drench and 19% by the 4 $mg \cdot L^{-1}$ paclobutrazol drench compared to the control groups that received no paclobutrazol liner drench

(Table 4.1, Figure 4.6). Average width was reduced 8% by 2 mg·L^{-1} paclobutrazol and 11% by 4 mg·L^{-1} paclobutrazol. There was no significant difference in the interaction or subplots for height and average width. No significant difference was seen for number of leaders or branches in either the main plot or subplot (data not presented).

Phytotoxicity was significant with 2 or 4 mg·L^{-1} paclobutrazol drenches compared to the plants that did not receive the drench (Table 4.1, Figure 4.2). An interaction between the paclobutrazol and branching PGR groups was found in regards to phytotoxicity. No significant difference was found between the branching agents that did not receive a paclobutrazol drench. At the 2 mg·L^{-1} paclobutrazol drench, phytotoxicity symptoms were not significantly different in the branching agent plants compared to the control plants. At the 4 mg·L^{-1} paclobutrazol drench, application of benzyladenine resulted in less phytotoxic symptoms than the control. Phytotoxicity symptoms differed depending on the branching agent used. The benzyladenine applied plants exhibited red discoloration along the margins of the leaves. This discoloration was slight and did not negatively impact the overall quality of the plant. Chlorosis was seen in the dikegulac sodium applied groups, and downward leaf cupping was seen in the ethephon applied groups. Both symptoms were mild but were somewhat visually displeasing, so the overall quality was slightly reduced.

At 4 weeks after the initial foliar PGR application, height was reduced 28% in the plants drenched with 2 mg·L^{-1} paclobutrazol and 39% in those drenched with 4 mg·L^{-1} paclobutrazol compared to the control groups (Table 4.2, Figure 4.7). There was no significant interaction between the two plots for plant height. In the comparison of branching agents, height was actually increased by benzyladenine compared to the controls, reduced 15% by ethephon, while dikegulac sodium had no effect. Average width was reduced 32% in the 2 mg·L^{-1} paclobutrazol drench plants and 41% in the 4 mg·L^{-1} paclobutrazol plants compared to the untreated control plants. There was a significant interaction between the paclobutrazol drench rate and branching agents for average plant width. For plants that did not receive the paclobutrazol drench, there was a 13% reduction in average width for those sprayed with benzyladenine, and a 32% reduction in growth in those sprayed with ethephon. Plants sprayed with dikegulac sodium were not significantly different from the control plants. For plants drenched with 2 mg·L^{-1} paclobutrazol, average width was unaffected by BA but reduced 30% by ethephon and 13% by dikegulac sodium. There was no significant difference in average width for plants drenched with 4 mg·L^{-1} paclobutrazol and subsequently subjected to branching PGRs.

The number of leaders was unaffected in plants drenched with 2 mg·L^{-1} but was reduced by the 4 mg·L^{-1} paclobutrazol drench compared to the control group (Table 4.2). There was no significant interaction between the paclobutrazol drench and branching agents applied for number of leaders. The branching agents did not affect the number of leaders compared to the control. The number of branches was reduced by both of the paclobutrazol drench rates compared to the control plants. There was a significant interaction between the paclobutrazol rates and branching agents for number of branches. Where there was no paclobutrazol application, all of the branching agents reduced number of branches as compared to the untreated control ,whereas the branching agents had no effect on plants previously subjected to the 2 and 4 mg·L^{-1} paclobutrazol drench.

Phytotoxicity continued to persist at the 4 week data collection and was found in all of the PGR applications (Table 4.2, Figure 4.2). Phytotoxicity was significant in those receiving the 2 mg·L^{-1} drench but more prevalent in the 4 mg·L^{-1} paclobutrazol drenched plants compared to the groups that did not receive paclobutrazol. There was a significant interaction between the paclobutrazol drenched plants and branching agents applied. Phytotoxicity was found in plants sprayed with benzyladenine or dikegulac sodium that did not receive the paclobutrazol drench. In plants drenched with 2 mg·L^{-1} paclobutrazol, there was no significant difference in the plants applied with branching agents compared to the control plants. In plants drenched with 4 mg·L^{-1} paclobutrazol, benzyladenine or ethephon caused more symptomatic plants than the control or dikegulac sodium. Benzyladenine consisted of leaf curling and discoloration on the leaves, and the ethephon phyto consisted of downward leaf cupping. Both of these symptoms reduced the visual quality of the plants but did not have a lasting impact since the plants outgrew these symptoms by the next data collection.

By 6 WAIT, height was reduced 27% by 2 mg·L^{-1} paclobutrazol group and 42% by the 4 mg·L^{-1} drench (Table 4.3, Figure 4.8). There was no interaction between the paclobutrazol drenches and branching agents in height. Height was not affected by benzyladenine but reduced 29% by ethephon or 19% by dikegulac sodium as compared to the control. Average width was reduced 24% by 2 mg·L^{-1} paclobutrazol and 36% by 4 mg·L^{-1} paclobutrazol compared to the plants that did not receive the drench application. There was no significant interaction between the paclobutrazol drenches and branching agents for average width. For the branching agents, although BA had no effect, average width was reduced 28% by ethephon and 9% by dikegulac sodium compared to the control. Number of leaders was decreased in both of the paclobutrazol drenches compared to the control group. There was an interaction in the number of leaders between the combined paclobutrazol drenches and branching agents. At 0 or 4 mg·L^{-1} paclobutrazol drench, there was no significant effect of branching agents. However, at the 2 mg·L^{-1} paclobutazol rate, both ethephon and dikegulac sodium had fewer leaders than the control group. The number of branches was decreased by both rates of the paclobutrazol drench. There was an interaction between the paclobutrazol drenches and branching agents for number of branches. For plants subjected to the 0 and 2 $mg \cdot L^{-1}$ paclobutrazol drench, there was no significant effect of branching agents. For plants drenched with 4 $mg \cdot L^{-1}$ paclobutrazol drench, benzyladenine, ethephon, and dikegulac sodium were all effective at increasing the number of branches compared to the control.

Marketability was rated at the 6 week data collection (Table 4.3). There was no significant difference in marketability between the paclobutrazol drenches. There was an interaction between the paclobutrazol and branching agent applications. At the 0 $mg \cdot L^{-1}$ paclobutrazol drench, only the application of ethephon resulted in a higher marketability rating compared to the control. The plants produced in the ethephon group were more compact and had tighter internodes, which is considered more desirable to consumers and more salable as a result. At the 2 $mg \cdot L^{-1}$ paclobutrazol rate, there was no significant difference between the branching agents and control. At the 4 $mg \cdot L^{-1}$ paclobutrazol drench, only plants sprayed with ethephon had lower marketability ratings compared to controls due to stunting and not filling out the pot.

By the final data collection (9 WAIT), plant height was reduced 15% by 2 $mg \cdot L^{-1}$ paclobutrazol and 23% by the 4 $mg \cdot L^{-1}$ paclobutrazol groups compared to the control groups (Table 4.4, Figure 4.9). There was no interaction in plant height between the paclobutrazol drenches and branching agents. In the branching agents, height was reduced 21% only in the ethephon group. Average width was reduced 14% by 4 $mg \cdot L^{-1}$ paclobutrazol drench compared to the control plants that did not receive the paclobutrazol drench application. There was no interaction in average plant height between the paclobutrazol drenches and branching agents. In the branching agent groups, width was reduced by 19% again only by ethephon compared to the controls. The number of leaders and the number of branches were decreased by both of the paclobutrazol drenches compared to the control. There was no interaction between the paclobutrazol drenches and branching agents in the number of branches or leaders. There was no significant differences between the branching agents and controls for number of branches or leaders.

Marketability was rated at the final data collection (Figure 4.5). There was a slightly higher marketability rating in the control group that did not receive a paclobutrazol drench compared to the groups that did receive the drenches (Table 4.4). The paclobutrazol drench groups had flimsy flower stalks that were not able to stand upright like the plants in the control groups. As a result, marketability was reduced. There was an interaction between the two plots for marketability rating. For plants that did not receive a paclobutrazol drench, only ethephon increased the marketability rating compared to the untreated controls. Application of ethephon resulted in shorter, more compact plants that had a more well-behaved growth habit compared to the other groups. No significant effects were seen in the 2 or 4 $mg \cdot L^{-1}$ paclobutrazol drenched plants subjected to branching PGRs. Because application of ethephon alone resulted in the most salable plants, the additional application of a growth retardant like paclobutrazol may not be necessary in producing marketable 'Red Rocks' plants.

The number of flower stalks were counted, and there were more flower stalks in the control group than in the paclobutrazol drench groups (Table 4.4). There was no interaction between the paclobutrazol drenches and branching agents for number of flower stalks. With respect to branching agents, benzyladenine had no effect while ethephon and dikegulac sodium reduced the number of flower stalks compared to the control. Days to flower were counted from the day of transplant until the day of first flower. The plants treated with the 4 $mg \cdot L^{-1}$ paclobutrazol rate took 2 days longer to flower than the plants that did not receive the drench treatment.

There was no interaction for days to flower between the main and subplots. All of the plants treated with a branching agent took longer to flower than the untreated control, with the ethephon group being longest, 4 days after the untreated control plants. Percent of plants flowering was evaluated. With either of the paclobutrazol drench rates, percent of plants flowering was decreased significantly by ethephon. Shoot dry weight was decreased by both rates of the paclobutrazol drench (Table 4.4). There was no significant interaction for shoot dry weight between the paclobutrazol drenches and branching agents. For the branching agents, only ethephon reduced shoot dry weight compared to the other branching agents.

'Pike's Peak Purple' At the time of initial application of PGRs (0 WAIT), there was no significant differences in plant height, plant average width, and number of leaders (data not presented, Figure 4.1). There was an interaction in the number of branches between the paclobutrazol drenches and branching agents. This interaction was not expected because all of the plants were supposed to be equally uniform in growth development and not significant in any of the variables measured. The PGRs were not yet applied, and so effects of the application were not yet prevalent. The significant interaction was found in the 2 $mg \cdot L^{-1}$ paclobutrazol drench groups subjected to branching agents. The dikegulac sodium group had more branches than the control group (7.9 vs. 5.4, respectively). Although this dikegulac sodium group had an early advantage in the number of branches before application of the PGRs, this difference was no longer seen by the 2 week data collection.

At 2 WAIT, height was reduced 16% in both rates of the paclobutrazol drench groups compared to the control group (Table 4.5, Figure 4.10). There was an interaction between the paclobutrazol drenches and the branching agent applications for plant height. For the plants that did not receive a paclobutrazol drench, benzyladenine reduced height 22% and ethephon reduced height 29%. With the 2 mg·L^{-1} paclobutrazol drench, height was increased by benzyladenine compared to the control group that did not receive a branching PGR. With the 4 mg·L^{-1} paclobutrazol drench, height was reduced 13% by benzyladenine, 36% by ethephon, and 16% by dikegulac sodium. Average plant width was not significantly different between the drench rates of paclobutrazol. There was no interaction between the paclobutrazol drenches and branching agents for average width. Average width was reduced 9% by benzyladenine and 15% by ethephon compared to the control. The number of leaders and branches were not significantly different in the paclobutrazol drench groups or branching agent groups (data not presented).

Phytotoxicity was found at 2 WAIT (Table 4.5, Figure 4.3). Application of the 4 mg·L^{-1} paclobutrazol drench resulted in a higher phytotoxicity rating than in groups that did not receive a drench application. There was an interaction between the paclobutrazol drench and branching agents for phytotoxicity. For groups that did not receive a paclobutrazol drench, application of benzyladenine resulted in higher phytotoxicity compared to the other groups. With the 2 mg·L^{-1} or 4 mg·L^{-1} paclobutrazol drench, phytotoxicity was more prevalent in the plants sprayed with benzyladenine or ethephon than in the control or dikegulac sodium plants. Application of benzyladenine resulted in red/purple discoloration along the shoot margins, and application of ethephon resulted in leaf cupping. Chlorosis was seen in the dikegulac sodium group. In addition to these symptoms, leaf twisting and distortion were found as well. Most of the phytotoxicity symptoms were mild and only slightly decreased visual quality. However, benzyladenine caused moderate symptoms in a few plants, which reduced quality considerably. These symptoms persisted for a few weeks, but the plants eventually grew out of the phytotoxicity.

At 4 weeks after the first PGR application, height was reduced 47% by the 2 mg·L^{-1} paclobutrazol drench and 57% by the 4 mg·L^{-1} paclobutrazol drench compared to the control plants (Table 4.6, Figure 4.11). There was a significant interaction between the paclobutrazol drenches and branching agents for plant height. In the groups that did not receive a paclobutrazol drench, benzyladenine reduced height 25%, and ethephon reduced height 36%. Dikegulac sodium did not significantly reduce height when compared to the control. However, where plants were drenched with 2 or 4 $mg \cdot L^{-1}$ paclobutrazol, there was no significant difference between the branching agents. Average width was reduced 41% by 2 $mg \cdot L^{-1}$ paclobutrazol and 50% by 4 $mg \cdot L^{-1}$ paclobutrazol. The interaction between the paclobutrazol drench and branching agent groups was significant for average plant width. In the groups that did not receive a paclobutrazol drench, average width was reduced 26% by benzyladenine and 41% by ethephon. In the groups that received either 2 $mg \cdot L^{-1}$ or 4 $mg \cdot L^{-1}$ paclobutrazol drenches, average width was reduced 30% by ethephon. Average width was not significantly reduced by either benzyladenine or ethephon in the plants drenched with paclobutrazol.

There was no significant difference in the number of leaders with the paclobutrazol drenches (Table 4.6). There was no interaction between the paclobutrazol drenches and branching agents for number of leaders. There were slightly more leaders in the benzyladenine group and fewer leaders in the ethephon group when compared to the controls. Number of branches was not significantly different between the paclobutrazol rates. There was no interaction in the number of branches between the paclobutrazol drenches and branching agents. There was an increase in the number of branches only in plants sprayed with benzyladenine compared to the other groups. Although ratings were low, phytotoxicity was persistent into the 4 WAIT data collection (Table 4.6, Figure 4.4). The 4 $mg \cdot L^{-1}$ paclobutrazol drench groups had higher phytotoxicity ratings compared to the control group. There was no significant interaction between the paclobutrazol drench and branching agents for phytotoxicity. In the branching agent groups, phytotoxicity was caused by benzyladenine or ethephon. Plants sprayed with benzyladenine exhibited red/purple discoloration along the mid-vein of the leaf. This discoloration was minor but did slightly reduce the visual quality of the plant. Plants sprayed with ethephon displayed slight leaf cupping that did not negativity impact the quality of the plant.

At 6 WAIT, there was a 48% height reduction in the 2 $mg \cdot L^{-1}$ paclobutrazol group and a 64% height reduction in the 4 $mg \cdot L^{-1}$ paclobutrazol group (Table 4.7, Figure 4.12). There was a significant interaction between the paclobutrazol drenches and the branching agents. In the groups that were not drenched with paclobutrazol, benzyladenine reduced height 19% and ethephon reduced height 29%. Height was not significantly affected by dikegulac sodium compared to the controls. There was no significant difference in plant height in the 2 $mg \cdot L^{-1}$ paclobutrazol drench groups subjected to branching agents. In the 4 $mg \cdot L^{-1}$ paclobutrazol drench groups, ethephon reduced height 24%, while benzyladenine and dikegulac sodium did not significantly reduce height compared to the control. Average width was reduced 43% by the 2 $mg \cdot L^{-1}$ paclobutrazol drench and 59% by the 4 $mg \cdot L^{-1}$ paclobutrazol drench. There was a significant interaction between the paclobutrazol drench and branching agents for average plant width. Benzyladenine reduced average width 25%, and ethephon reduced average width 32% in the plants not drenched with paclobutrazol. With the 2 $mg \cdot L^{-1}$ paclobutrazol drench, average width was reduced 18% by benzyladenine and 31% by ethephon. In the 4 $mg \cdot L^{-1}$ paclobutrazol drench groups, ethephon was the only branching agent to reduce plant width.

The number of leaders was reduced with both rates of the paclobutrazol drench compared to the untreated control (Table 4.7). There was no interaction for number of leaders between the paclobutrazol drenches and branching agents. There were fewer leaders in the ethephon group compared to the other groups. The number of branches was decreased in plants drenched with either rate of paclobutrazol. There was an interaction between the paclobutrazol drench and branching agents for the number of branches. In the groups that were not drenched with paclobutrazol, application of benzyladenine or ethephon resulted in fewer branches than the control. Dikegulac sodium had no effect as compared to the controls. There was no significant difference between the branching agents in plants drenched with 2 $mg \cdot L^{-1}$ paclobutrazol. With the 4 $mg \cdot L^{-1}$ paclobutrazol drench plants subjected to branching agents, benzyladenine had no effect on the number of branches, but the plants sprayed with ethephon or dikegulac sodium had fewer branches than the control plants.

Marketability was rated at the 6 WAIT data collection (Table 4.7). Both rates of the paclobutrazol drenches were reduced in marketability compared to the control. This reduced marketability was due to plant stunting and little pot fill. As a result, the plants drenched with paclobutrazol were not considered salable, while the control plants did have some salability. There was no interaction between the paclobutrazol drenches and branching agents. Plants sprayed with ethephon had a lower marketability rating than the other groups due to over-regulation and stunting. As a result of this stunting, plants sprayed with ethephon were not considered salable.

AT 10 WAIT, height was reduced 18% by the 2 $mg \cdot L^{-1}$ paclobutrazol drench and 38% by the 4 $mg \cdot L^{-1}$ paclobutrazol drench compared to the control group (Table 4.8, Figure 4.13). There was an interaction between the paclobutrazol drench and branching agents. In plants not drenched with paclobutrazol, there was no significant difference in plant height between the branching agents. With the 2 $mg \cdot L^{-1}$ paclobutrazol drenched plants subjected to branching agents, ethephon reduced height by 19%, but application of benzyladenine or dikegulac sodium did not significantly reduce height when compared to the control. With the 4 mg·L^{-1} paclobutrazol drench, height was reduced 38% by ethephon, but no other branching agent significantly reduced height. Average plant width was reduced 29% by the 2 mg·L^{-1} paclobutrazol drench and 47% by the 4 mg·L^{-1} paclobutrazol drench. There was no significant interaction between the paclobutrazol drenches and branching agents for average plant width. For the branching agents, average plant width was reduced 11% by benzyladenine and 23% by ethephon when compared to the control, while dikegulac sodium had no significicnant effect as compared to the control for average plant width.

The number of leaders was decreased in both rates of the paclobutrazol drench when compared to the control (Table 4.8). A significant interaction occurred between the paclobutrazol drenches and branching agents. There was no significant difference in the effect of branching agents in plants not drenched with paclobutrazol for number of leaders. With the 2 mg·L^{-1} paclobutrazol drenched plants subjected to branching agents, ethephon or dikegulac sodium had more leaders than the control. Benzyladenine did not significantly increase the number of leaders. With the 4 mg·L^{-1} paclobutrazol drenched plants subjected to branching agents, only ethephon sprayed plants had fewer leaders than the other groups. The number of branches was decreased by both of the paclobutrazol drench applications compared to the control. There was a significant interaction in the number of branches between the paclobutrazol drenches and branching agents. There was no significant difference in the number of branches for the plants drenched with 0 or 2 mg·L^{-1} paclobutrazol subjected to branching agents. However, with the 4 mg·L^{-1} paclobutrazol drench, plants sprayed with ethephon had fewer branches compared to the other groups.

Marketability was rated at the final data collection (Table 4.9, Figure 4.5). Plants drenched in either rate of paclobutrazol had higher marketability ratings than the control plants. The control plants had an average marketability of 2, which is not considered salable due to their unruly, non-upright growth habit and straggly flower stalks. The paclobutrazol drenched plants were more compact but not completely upright, and so were only marginally salable. There was an interaction between the paclobutrazol drenches and branching agents for marketability. There was no significant difference in the marketability rating for the 0 and 2 mg·L^{-1} paclobutrazol drench plants subjected to branching agents. For plants drenched with 4 mg·L^{-1} paclobutrazol and subjected to a branching agent application, those sprayed with benzyladenine had the highest marketability ratings when compared to the other groups. The combination of a 4 mg·L^{-1} paclobutrazol drench and benzyladenine produced compact and upright plants with erect flower stalks. This combination produced the most salable plants out of all the applications. This group did not receive the highest rating possible because the plants did not have a full appearance and had not completely filled out the pot. Overall, the combination of 4 mg·L^{-1} paclobutrazol applied as a drench and 600 mg·L^{-1} benzyladenine applied as a foliar spray is recommended in producing more salable plants and in controlling the vigorous growth habit of 'Pike's Peak Purple.'

The number of flower stalks was also evaluated (Table 4.9). The least number of flower stalks were found in in the 4 mg·L^{-1} paclobutrazol rate group. Number of flower stalks was also reduced in the 2 mg·L^{-1} paclobutrazol drench group compared to the control. There was an interaction between the paclobutrazol drenches and the branching agents for number of flower stalks. For plants not drenched with paclobutrazol, application of benzyladenine or ethephon resulted in the least amount of flower stalks compared to the control group. Application of dikegulac sodium had no significant effect compared to the control group. In the 2 mg·L^{-1} paclobutrazol drench groups subjected to branching agents, application of dikegulac sodium resulted in the most flower stalks and application of ethephon resulted in the least flower stalks. Application of benzyladenine did not affect number of flower stalks. At the 4 $mg \cdot L^{-1}$ paclobutrazol drench, ethephon decreased the number of flower stalks compared to the other groups. For days to flower, both rates of the paclobutrazol drench caused delays in flowering. The 2 $mg \cdot L^{-1}$ rate of paclobutrazol delayed flowering by two days, and the 4 $mg \cdot L^{-1}$ rate of paclobutrazol delayed flowering by 4 days. There was no interaction in days to flower between the paclobutrazol drenches and branching agents. Benzyladenine delayed flowering by 5 days and ethephon delayed flowering by 6 days when compared to the control plants. Dikegulac sodium did not significantly delay flowering when compared to the control. The percent of plants flowering was significantly reduced in the 4 $mg \cdot L^{-1}$ paclobutrazol drench groups subjected to a branching agent application of either benzyladenine or ethephon. Shoot dry weight was measured and found to be significantly reduced with both drench rates of paclobutrazol when compared to the control. There was a significant interaction between the paclobutrazol drenches and branching agents. For plants not drenched with paclobutrazol, benzyladenine and ethephon reduced shoot dry weight when compared to the control. At the 2 and 4 $mg \cdot L^{-1}$ paclobutrazol drench rates subjected to branching agents, ethephon was the only PGR to reduce shoot dry weight.

Discussion

Overall, the application of paclobutrazol and branching agents affected ‘Red Rocks’ and ‘Pike’s Peak Purple’ differently by the final data collections. The combination of the PGRs produced smaller and more compact plants, but ‘Red Rocks’ was beginning to outgrow these treatments by the final data collection. Although the paclobutrazol drenched ‘Red Rocks’ plants were shorter, the flower stalks did not stay fully upright and so created an undesirable growth habit. The most marketable ‘Red Rocks’ crops produced were those that did not receive a paclobutrazol drench but received any one of the branching agent applications. The ethephon branching group had the highest marketability rating. This leads to the conclusion that a separate growth retardant application is not necessary for producing marketable ‘Red Rocks’ plants in the industry, but suggests that two applications of a branching PGR such as ethephon may produce a good quality containerized *Penstemon*. Research has shown that ethephon can act both as a growth retardant and as a branching agent, and in this case, may have enough of an effect to substitute for an additional application of a growth retardant. Starman et al. (2004) found that ethephon was efficient as a growth retardant in regulating and reducing growth in vegetative annuals. Based on the results of this study, it is recommended that growers pinch ‘Red Rocks’ once during the liner stage and then apply ethephon as a foliar spray twice, once during the liner stage and then again after transplant, at a rate of 500 $mg \cdot L^{-1}$. Growers will need to be advised that these ethephon applications may delay flowering in this particular crop. Flowering delays due to ethephon applications have also been seen in other herbaceous perennials such as *Gaillardia pulchella* (Hammond et al., 2007) and in *Monarda*, *Physostegia*, and *Echinacea* (Hayashi et al., 2001).

On the other hand, ‘Pike’s Peak Purple’ responded well to the combination of the paclobutrazol drenches and branching agents. By the end of the study, the most marketable plants were produced with the combination of the 4 $mg \cdot L^{-1}$ paclobutrazol drench plus two foliar applications of benzyladenine. Plants that received the lower rate of paclobutrazol or no drench at all outgrew the PGR effects by the final data collection and formed a less-upright habit that was reduced in quality and marketability. ‘Pike’s Peak Purple’ appears to have a more vigorous and troublesome growth habit when grown in a container compared to ‘Red Rocks’ and so requires more growth control. It is recommended that growers pinch 'Pike's Peak Purple' during the liner stage and then apply a branching PGR such as benzyladenine once during the liner stage and then again after transplant. Other studies have also proven that two applications of PGRS before and after transplant are effective at enhancing plant quality. Grossman et al. (2013) found that applying either benzyladenine or dikegulac sodium twice resulted in more branching in several herbaceous perennials. In addition to applying branching agents, an application of a growth retardant such as paclobutrazol will be necessary in order to regulate growth further and help promote a shorter and more compact 'Pike's Peak Purple' plant. Application of paclobutrazol as a drench was found to be effective at controlling growth in 'Pike's Peak Purple' when it was applied before transplant in the liner stage. Gent (2004) also found that applying a paclobutrazol drench to rhododendron before transplant was most effective at inhibiting stem elongation. In summary, pinching techniques, multiple applications of a branching agent, and application of a growth retardant are necessary in regulating the growth of 'Pike's Peak Purple' while in the container.

Literature Cited

Bañón, S., A. González, E.A. Cano, J.A. Franco, and J.A. Fernández. 2002. Growth, development and colour response of potted *Dianthus caryophyllus* cv. Mondriaan to paclobutrazol treatment. *Scientia Horticulturae* 94: 371-377.

Cochran, D.R., A. Fulcher, and G. Bi. 2013. Efficacy of dikegulac sodium applied to pruned and unpruned 'Limelight' Hydrangea grown at two locations in the southeastern United States. HortTechnology 23(6): 836-842.

Dole, J. M., and H. F. Wilkins. 2005. Plant growth regulation, p.141-161. In: Floriculture: principles and species. 2nd ed. Prentice Hall, Upper Saddle River, N.J.

Gent, M.P.N. 2004. Efficacy and persistence of paclobutrazol applied to rooted cuttings of rhododendron before transplant. HortScience 39(1):105-109.

Gibson, J.L. and B.E. Whipker. 2003. Efficacy of plant growth regulators on the growth of vigorous Osteospermum cultivars. HortTechnology 13(1):132-135.

Grossman, M., J. Freeborn, H. Scoggins, and J. Latimer. 2013. Timing of benzyladenine and dikegulac sodium application affects branching of liners and finished herbaceous perennial plants. HortScience 48(7):875-882.

Hammond, H.E., R.K. Schoellhorn, S.B. Wilson, and J.G. Norcini. 2007. Differing blanketflower cultivar and ecotype responses to plant growth regulators. HortTechnology 17(4):552-556.

Hayashi, T., R.D. Heins, A.C. Cameron, and W.H. Carlson. 2001. Ethephon influences flowering, height, and branching of several herbaceous perennials. Scientia Horticulture 91:305-323.

Latmer, J.G. 2004. Trends and uses of plant growth regulators on herbaceous perennials. Proc. Ann. Conf. Plant Growth Regulator Society Amer. 31:1-4.

Latimer, J. and J. Freeborn. 2009. New Uses of PGRs in ornamentals: Configure (6-BA) increases branching of herbaceous perennials. Proc. Plant Growth Regulat. Soc. Amer. 36:88-93.

Pilon, P. 2006. Controlling plant height of perennial crops, p.201-248. In: Perennial solutions: a grower's guide to perennial production. Ball, Batavia, IL.

Richards D. and Wilkinson, R.I., 1984. Effect of manual pinching, potting-on and cytokinins on branching and flowering of *Camellia, Rhododendron* and *Rosa*. *Scientia Horticulture.*, 23: 75-83.

Starman, T.W. 1991. Response of Kientzler New Guinea impatiens to manual and chemical pinching. HortScience 26(7): 856-857.

Starman, T.W., M.C. Robinson, and K.L. Eixmann. 2004. Efficacy of ethephon on vegetative annuals. HortTechnology 14(1): 83-87.

Table 4.1. Plant height, average width, and phytotoxicity rating of *Penstemon x mexicali* 'Red Rocks' at 2 weeks after the initial application of PGRs (WAIT). Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Phytotoxicity Rating		
Paclobutrazol					
0	5.4a[z]	10.8a		0.3b	
2	4.7b	9.9b		0.7a	
4	4.4b	9.6b		0.8a	
Paclo. rate effect	<0.0001	<0.0001		<0.0001	
LSD	0.4	0.6		0.2	
Branching agent			0	2	4
0	4.8	10.0	0.0	0.6ab	0.9a
Benzyladenine 600	4.9	9.7	0.4	0.3b	0.3b
Ethephon 500	4.5	10.1	0.5	1.0a	1.0a
Dikegulac 600	5.1	10.4	0.5	0.9a	1.0a
Branching effect	0.0704	0.2319	0.1183	0.0034	<0.0001
LSD	0.5	0.7	0.5	0.4	0.3
Paclo. Rate*Branching effect	0.7472	0.8646		0.0216	

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.2. Plant height, average width, number of leaders, number of branches, and phytotoxicity of *Penstemon x mexicali* 'Red Rocks' at 4 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the sub-plot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate (mg·L^{-1})	Plant height (cm)	Plant width (cm)			Number of leaders	Number of branches			Phytotoxicity Rating		
Paclobutrazol											
0	8.5a[z]		17.3a		4.4a		18.6a			0.5c	
2	6.1b		11.8b		4.0ab		16.4b			1.2b	
4	5.2c		10.3c		3.7b		14.8b			1.4a	
Paclo. rate effect	<0.0001		<0.0001		0.0369		0.0021			<0.0001	
LSD	0.70		1.10		0.6		2.3			0.3	
Branching agent		0	2	4		0	2	4	0	2	4
0	6.7b	19.9a	13.6a	9.9	4.1	24.8a	17.0	12.5	0.0b	1.3ab	1.0c
Benzyladenine 600	7.5a	17.4b	12.6ab	11.4	4.2	16.6b	18.1	16.3	1.0a	1.1b	1.8b
Ethephon 500	5.7c	13.6c	9.5c	9.6	3.8	15.8b	14.8	15.8	0.0b	1.6a	2.0a
Dikegulac 600	6.5b	18.1ab	11.8b	10.2	3.9	17.4b	15.9	14.9	0.9a	0.9b	1.0c
Branching effect	<0.0001	<0.0001	<0.0001	0.1228	0.7041	0.0052	0.4006	0.0960	<0.0001	0.0133	<0.0001
LSD	1.1	2.0	1.4	1.6	0.7	5.2	4.2	3.2	0.2	0.4	0.2
Paclo. rate*Branching effect	0.6424		0.0002		0.2340		0.0011			<0.0001	

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.3. Plant height, average width, number of leaders, number of branches, and marketability of *Penstemon x mexicali* 'Red Rocks' at 6 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the sub-plot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate (mg·L^{-1})	Plant height (cm)	Plant width (cm)	Number of Leaders			Number of Branches			Marketability rating		
Paclobutrazol											
0	17.5a^{z}	27.8a		6.9a			59.4a			4.1	
2	12.8b	21.2b		4.5b			31.7b			4.1	
4	10.1c	17.8c		4.4b			26.9b			3.9	
Paclo. rate effect	<0.0001	<0.0001		<0.0001			<0.0001			0.4737	
LSD	1.5	2.1		0.6			6.5			0.3	
Branching agent			0	2	4	0	2	4	0	2	4
0	15.1a	25.0a	7.9	5.3a	3.6	71.0	36.6	18.3	4.0b	4.0ab	4.4a
Benzyladenine 600	15.8a	23.3ab	6.5	4.6ab	5.0	55.5	32.3	29.4	4.0b	4.1ab	3.9a
Ethephon 500	10.8c	17.9c	6.6	4.3b	4.8	57.6	27.3	30.3	4.5a	3.6b	3.0b
Dikegulac 600	12.3b	22.7b	6.6	3.9b	4.1	53.6	30.6	29.8	3.9b	4.5a	4.5a
Branching effect	<0.0001	<0.0001	0.1464	0.0273	0.1170	0.1184	0.4808	0.0512	0.0028	0.0336	0.0005
LSD	2.2	3.0	1.4	0.9	1.2	15.6	12.3	9.8	0.3	0.6	0.7
Paclo. rate*Branching effect	0.5017	0.1539		0.0200			0.0236			<0.0001	

^{z}Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.4. Plant height, width, number of leaders and branches, marketability, flower stalks, days to flower, flowering percentage, and dry weight of *Penstemon x mexicali* ‘Red Rocks’ at 9 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot.   Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Number of Leaders	Number of Branches	Marketability rating			Number of flower stalks	Days to Flower[y]	Percent plants flowering (%)			Shoot dry weight (g)
Paclobutrazol													
0	38.4a[z]	45.5a	8.3a	149a	3.7a			6.4a	50b	--[w]			13.3a
2	32.6b	43.2a	7.2b	103b	3.3b			5.1b	50ab	--			8.80b
4	29.4c	39.0b	6.5b	87.6c	3.1b			5.1b	52a	--			6.29c
Paclo. rate effect	<0.0001	0.0013	<0.0001	<0.0001	0.0086			0.0011	0.0398	--			<0.0001
LSD	3.4	3.9	0.8	11.2	0.4			1.0	--[x]	--			1.6
Branching agent					0	2	4			0	2	4	
0	35.7a	45.6a	8.0	117	3.0b	3.1	3.4	6.8a	49c	100%	100%	100%	10.9a
Benzyladenine 600	35.9a	45.6a	7.0	111	3.6ab	3.1	3.0	6.1ab	50b	100%	100%	100%	10.1a
Ethephon 500	28.2b	36.9b	7.3	117	4.3a	3.3	2.6	4.0c	53a	87.5%	50%	50%	7.53b
Dikegulac 600	34.2a	42.1a	7.0	108	3.8ab	3.6	3.5	5.4b	51b	87.5%	87.5%	100%	9.38a
Branching effect	<0.0001	<0.0001	0.0546	0.3579	0.0281	0.2710	0.0762	<0.0001	<0.0001	0.4063	0.0140	0.0046	0.0029
LSD	4.1	4.3	1.0	19.8	0.8	0.6	0.7	1.0	1.7	--	--	--	2.3
Paclo. rate*Branching effect	0.1999	0.2310	0.5051	0.0926	0.0102			0.3894	0.6569	--			0.1630

[z]Means within a column followed by the same letter are not significantly different (Student’s t-test, $P<0.05$, $n=8$).
[y]Days to flower were measured from the day of transplant to the day of first open flower.
[x]LSD not available for flowering data due to not all plants flowering in the PGR groups.
[w]Percent Plants flowering data analyzed as a nominal variable (yes/no) under contingency analysis in JMP. Data could not be analyzed as a split plot.

Table 4.5. Plant height, average width, and phytotoxicity of *Penstemon x mexicali* ‘Pike’s Peak Purple’ at 2 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate (mg·L^{-1})	Plant height (cm)			Plant width (cm)	Phytotoxicity Rating		
Paclobutrazol							
0		5.5a^{z}		8.9		0.4b	
2		4.6b		8.7		0.6ab	
4		4.6b		8.5		0.7a	
Paclo. rate effect		<0.0001		0.2518		0.0419	
LSD		0.5		0.6		0.3	
Branching agent	0	2	4		0	2	4
0	6.5a	4.1b	5.5a	9.3a	0.0b	0.1b	0.5b
Benzyladenine 600	5.1bc	5.3a	4.8b	8.5b	1.5a	1.1a	1.0a
Ethephon 500	4.6c	4.4b	3.5c	7.9c	0.3b	1.0a	1.0a
Dikegulac 600	5.8ab	4.8ab	4.6b	9.0ab	0.0b	0.0b	0.3b
Branching effect	0.0016	0.0462	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
LSD	0.9	0.8	0.7	0.6	0.5	0.3	0.4
Paclo. rate*Branching effect		0.0002		0.0586		0.0002	

^{z}Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).

Table 4.6. Plant height, average width, number of leaders, number of branches, and phytotoxicity of *Penstemon x mexicali* 'Pike's Peak Purple' at 4 weeks after the initial foliar PGR application (WAIT). Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)			Plant width (cm)			Number of Leaders	Number of Branches	Phytotoxicity Rating
Paclobutrazol									
0		11.8a[z]			18.1a		2.1	10.0	0.3b
2		6.3b			10.6b		2.3	9.6	0.5ab
4		5.1c			9.1c		2.1	9.4	0.6a
Paclo. rate effect		<0.0001			<0.0001		0.4399	0.5642	0.0204
LSD		0.9			1.4		0.4	1.3	0.4
Branching agent	0	2	4	0	2	4			
0	14.0a	6.3	5.8	22.0a	11.8a	10.1a	2.2b	9.1b	0c
Benzyladenine 600	10.5b	7.1	5.1	16.4b	10.9a	10.1a	2.9a	11.8a	1.3a
Ethephon 500	9.0b	5.6	4.5	12.9c	8.3b	7.1b	1.6c	8.8b	0.5b
Dikegulac 600	13.8a	6.4	4.9	20.8a	11.3a	9.2a	2.0bc	9.0b	0c
Branching effect	<0.0001	0.1628	0.0675	<0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001
LSD	1.7	1.3	0.9	2.1	1.6	1.2	0.4	1.3	0.3
Paclo. rate*Branching effect		<0.0001			<0.0001		0.2583	0.6342	0.1348

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.7. Plant height, average width, number of leaders, number of branches, and marketability of *Penstemon x mexicali* 'Pike's Peak Purple' at 6 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate (mg·L^{-1})	Plant height (cm)			Plant width (cm)			Number of leaders	Number of branches			Marketability Rating
Paclobutrazol											
0		20.6a^z			28.7a		4.2a		30.9a		3.9a
2		10.7b			16.4b		2.9b		14.0b		2.9b
4		7.5c			11.8c		2.5b		11.7b		2.5c
Paclo. rate effect		<0.0001			<0.0001		<0.0001		<0.0001		<0.0001
LSD		1.5			2.0		0.6		3.9		0.2
Branching agent	0	2	4	0	2	4		0	2	4	
0	23.8a	11.1	8.3a	34.2a	18.7a	13.3a	3.7a	40.4a	14.0	14.5a	3.3a
Benzyladenine 600	19.4bc	11.5	7.6ab	25.5b	15.3b	11.7a	3.7a	28.3bc	16.1	13.6a	3.2a
Ethephon 500	16.8c	8.6	6.3b	23.4b	13.0b	9.1b	2.1b	20.1c	13.1	8.3b	2.8b
Dikegulac 600	22.5ab	11.5	8.0a	31.6a	18.5a	13.2a	3.3a	34.8ab	12.8	10.5b	3.2a
Branching effect	0.0004	0.0907	0.0412	<0.0001	<0.0001	<0.0001	<0.0001	0.0022	0.5423	0.0009	<0.0001
LSD	3.1	2.6	1.5	3.5	2.4	1.7	0.7	10.1	5.1	3.1	0.4
Paclo. rate*Branching effect		0.0283			0.0023		0.2301		0.0014		0.3471

^{z}Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.8. Plant height, average width, number of leaders, and number of branches of *Penstemon x mexicali* 'Pike's Peak Purple' at 10 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)			Plant width (cm)	Number of Leaders			Number of Branches		
Paclobutrazol										
0		52.5a[z]		61.1a		6.7a			128a	
2		42.9b		43.4b		4.8b			67.5b	
4		32.7c		32.5c		3.8c			46.7c	
Paclo. rate effect		<0.0001		<0.0001		<0.0001			<0.0001	
LSD		3.0		3.9		0.5			9.0	
Branching agent	0	2	4		0	2	4	0	2	4
0	52.0	46.1a	37.6a	50.3a	7.5	4.0c	4.6a	144	64.6	49.3a
Benzyladenine 600	53.0	42.0ab	33.4a	44.6b	6.1	4.4bc	3.6ab	119	63.9	58.9a
Ethephon 500	49.6	37.3b	23.5b	38.9c	6.8	4.9b	3.0b	119	68.4	31.8b
Dikegulac 600	55.5	46.4a	36.4a	48.8a	6.5	5.9a	4.0ab	129	73.3	47.0a
Branching effect	0.1038	0.0021	<0.0001	<0.0001	0.1892	0.0004	0.0437	0.0904	0.4633	0.0047
LSD	4.7	5.0	4.7	7.8	1.3	0.8	1.1	22.1	13.3	14.0
Paclo. rate*Branching effect		0.0434		0.0716		0.0026			0.0156	

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).

Table 4.9. Marketability, number of flower stalks, days to flower, percent plants flowering, and shoot dry weight of *Penstemon x mexicali* 'Pike's Peak Purple' at 10 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot. Paclobutrazol liner drenches were applied at 10 mL per plant the day prior to potting.

PGR rate (mg·L^{-1})	Marketability scale			Number of flower stalks			Days to Flower[x]	Percent Plants Flowering (%)			Shoot dry weight (g)		
Paclobutrazol													
0		2.0b[z]			5.8a		53c		--[v]			17.9a	
2		3.2a			3.9b		55b		--			8.24b	
4		3.3a			2.9c		57a		--			4.67c	
Paclo. rate effect		<0.0001			<0.0001		<0.0001		--			<0.0001	
LSD		0.2			0.6		--		--			1.6	
Branching agent	0	2	4	0	2	4		0	2	4	0	2	4
0	2.0	3.1	3.1bc	7.1a	3.9b	3.6a	52b	100%	100%	100%	21.3a	9.08a	5.81a
Benzyladenine 600	2.0	3.3	3.8a	4.5c	3.6bc	2.9a	57a	88%	75%	50%	16.1b	8.31a	4.81a
Ethephon 500	2.0	3.4	2.8c	5.4bc	3.0c	1.9b	58a	100%	75%	13%	13.6b	5.53b	2.82b
Dikegulac 600	2.0	3.1	3.6ab	6.0ab	5.0a	3.4a	53b	100%	100%	100%	20.7a	10.04a	5.26a
Branching effect	--[y]	0.7191	0.0024	0.0039	0.0004	0.0055	<0.0001	0.4119	0.1060	<0.0001	0.0001	0.0032	0.0001
LSD	--	0.5	0.5	1.4	0.8	0.9	--[w]	--	--	--	3.4	2.3	1.2
Paclo. rate*Branching effect		0.0019			0.0085		0.6867		--			0.0166	

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, P<0.05, n=8).
[y]P-value and LSD data not available due to no difference in number of leaders between PGR groups.
[x]Days to flower were measured from the day of transplant to the day of first open flower.
[w]LSD not available for flowering data due to not all plants flowering in the PGR groups.
[v]Percent Plants flowering data analyzed as a nominal variable (yes/no) under contingency analysis in JMP. Data could not be analyzed as a split plot.

Figure 4.1. *Penstemon x mexicali* ‘Red Rocks’ (top photo) and ‘Pike’s Peak Purple (bottom photo) pinched liners at the time of the initial foliar PGR application (0 WAIT).

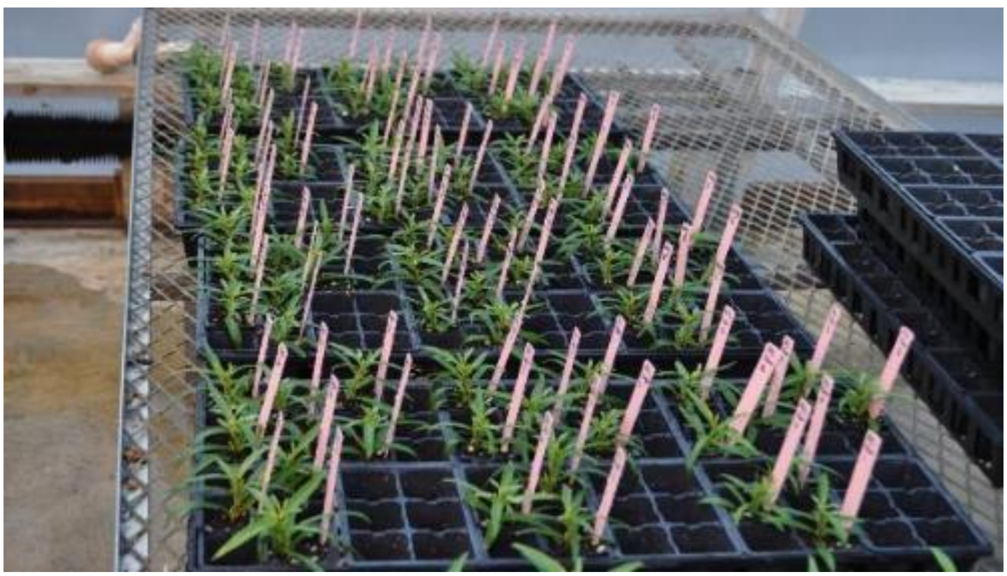


Figure 4.2. *Penstemon x mexicali* 'Red Rocks' displaying phytotoxicity symptoms at 2 weeks (top photos) and 4 weeks (bottom photos) after initial PGR application . Top photos: the photo on the left shows a plant with mild chlorosis on the shoots after application of 600 mg·L^{-1} dikegulac sodium, and the photo on the right shows a plant with downward leaf cupping after 500 mg·L^{-1} ethephon. Bottom photos: The photo on the left shows a plant with leaf curling and red discoloration on the shoot margins after application of 600 mg·L^{-1} benzyladenine spray and 4 mg·L^{-1} paclobutrazol drench, and the photo on the right shows a plant with downward leaf cupping after application of 500 mg·L^{-1} ethephon spray and 4 mg·L^{-1} paclobutrazol drench.

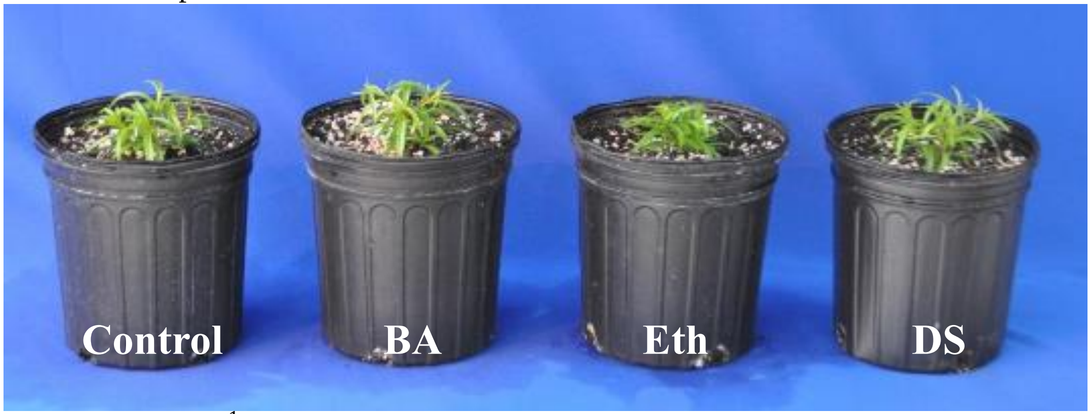
Figure 4.3. *Penstemon x mexicali* 'Pike's Peak Purple' displaying phytotoxicity symptoms at 2 weeks after initial PGR application: 1-mild downward leaf cupping and twisting, 2-mild red discoloration on shoot margins, 3-leaf distortion and twisting, and 4-leaf twisting and distortion and red discoloration on shoot margins.

Figure 4.4. *Penstemon x mexicali* ‘Pike’s Peak Purple’ displaying phytotoxicity symptoms at 4 weeks after initial PGR application (Top photo: red/purple discoloration on the middle vein of the leaf after application of 600 $mg{\cdot}L^{-1}$ benzyladenine, Bottom photo: downward leaf cupping after application of 500 $mg{\cdot}L^{-1}$ ethephon).

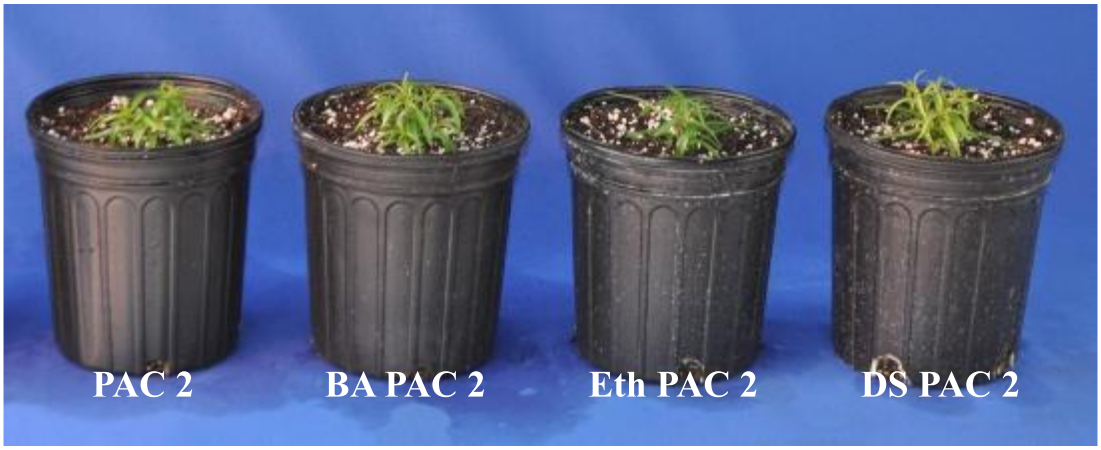
Figure 4.5. *Penstemon x mexicali* ‘Red Rocks’ (top photo) marketability plants at 9 weeks after the initial application of PGRs (WAIT) and ‘Pike’s Peak Purple’ (bottom photo) marketability plants at 10 weeks after the initial application of PGRs. The plants were rated on a scale of 1 to 5 on marketability: ‘Red Rocks’ (left to right) 2, 3, 4, and 5, ‘Pike’s Peak Purple’ (left to right) 1, 2, 3, and 4.

Figure 4.6. *Penstemon x mexicali* ‘Red Rocks’ plants at 2 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench



b. 2 mg·L^{-1} paclobutrazol drench



c. 4 mg·L^{-1} paclobutrazol drench

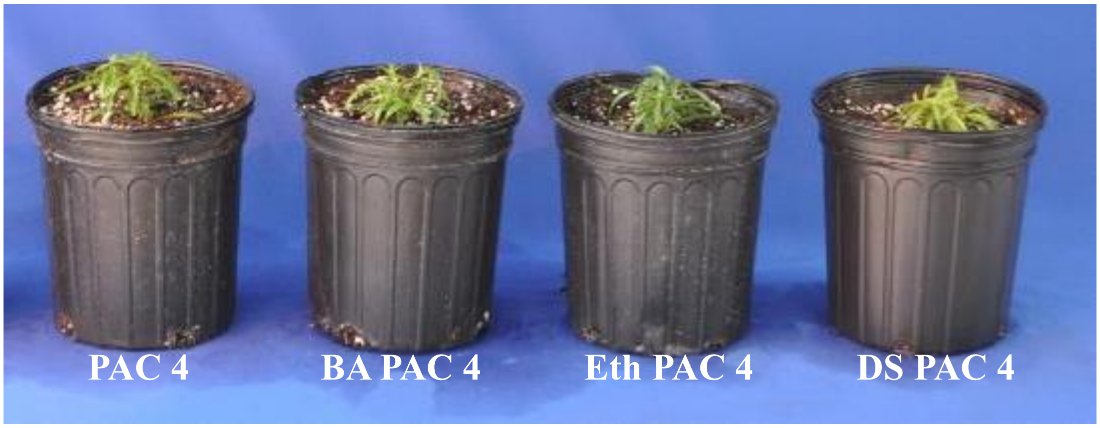
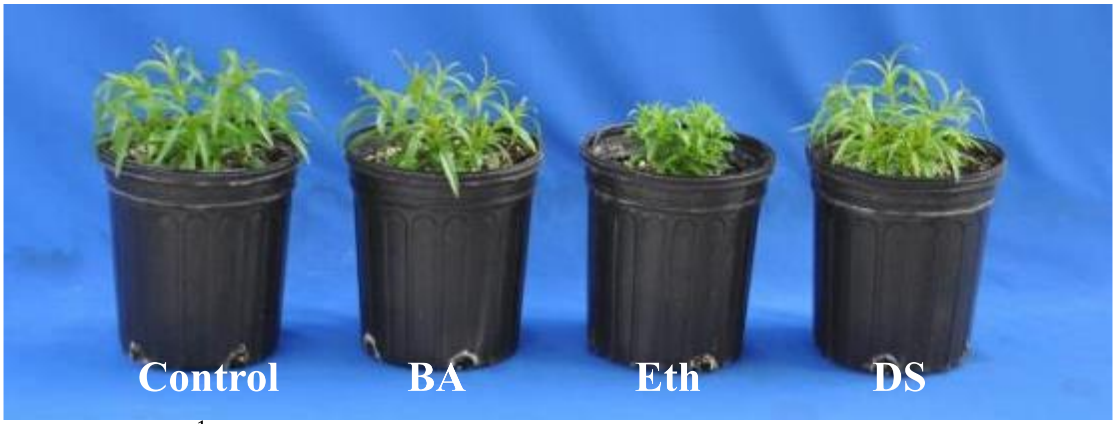


Figure 4.7. *Penstemon x mexicali* 'Red Rocks' plants at 4 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench

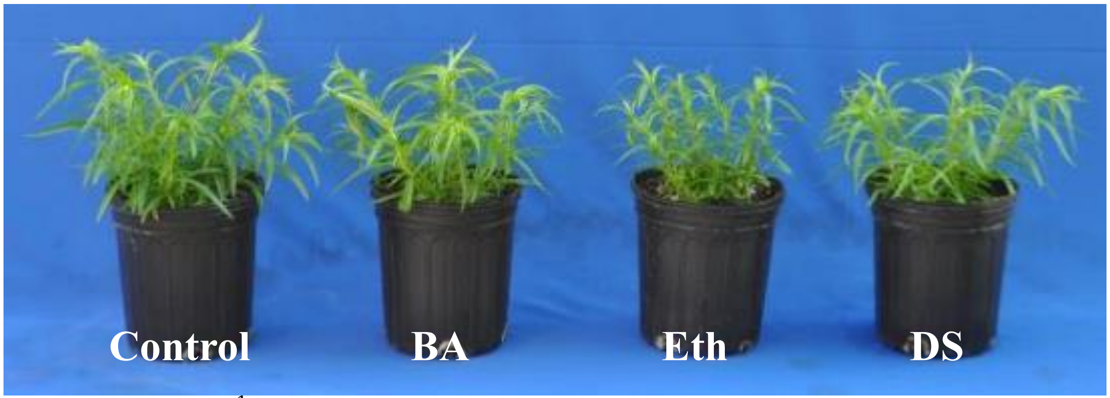


b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench

Figure 4.8. *Penstemon x mexicali* ‘Red Rocks’ plants at 6 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench

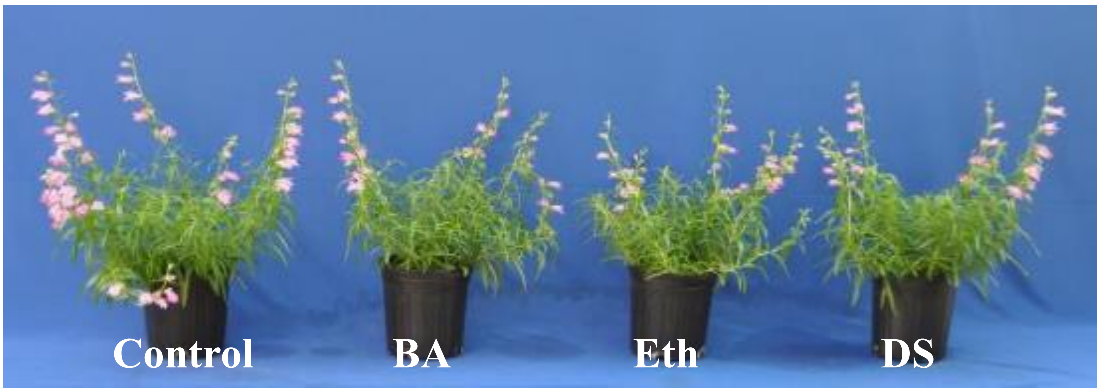


b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench

Figure 4.9. *Penstemon x mexicali* ‘Red Rocks’ plants at 9 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench

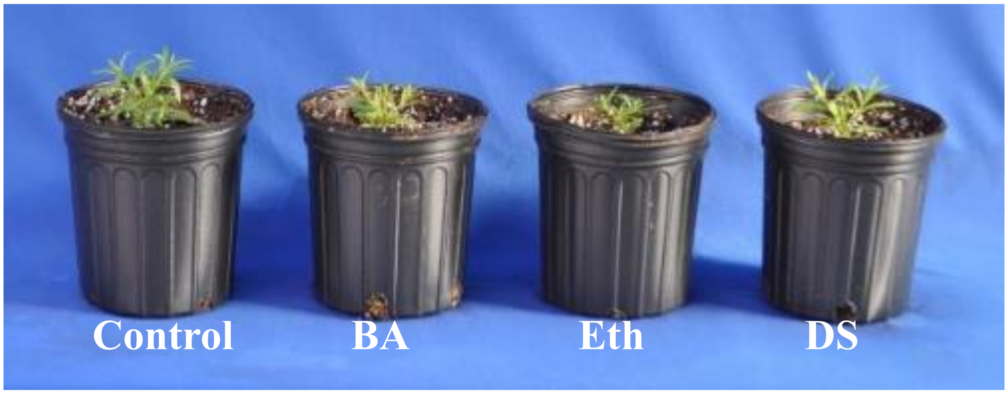


b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench

Figure 4.10. *Penstemon x mexicali* 'Pike's Peak Purple' plants at 2 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench



b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench

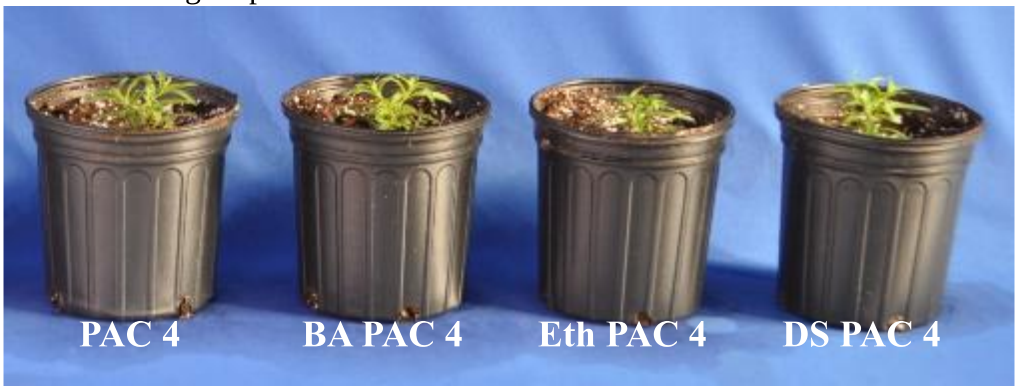
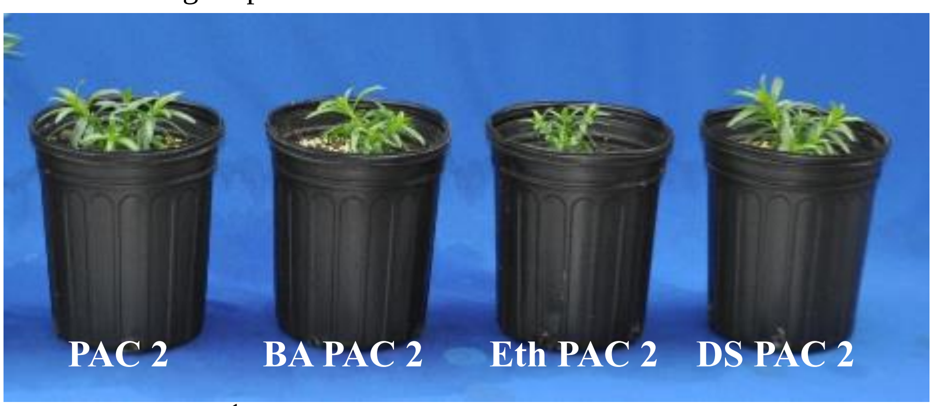


Figure 4.11. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 4 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 $mg{\cdot}L^{-1}$ benzyladenine (BA) spray, 500 $mg{\cdot}L^{-1}$ ethephon (Eth) spray, 600 $mg{\cdot}L^{-1}$ dikegulac sodium (DS) spray, 2 $mg{\cdot}L^{-1}$ paclobutrazol liner drench (PAC 2), or 4 $mg{\cdot}L^{-1}$ paclobutrazol liner drench (PAC 4).

a. No paclobutrazol

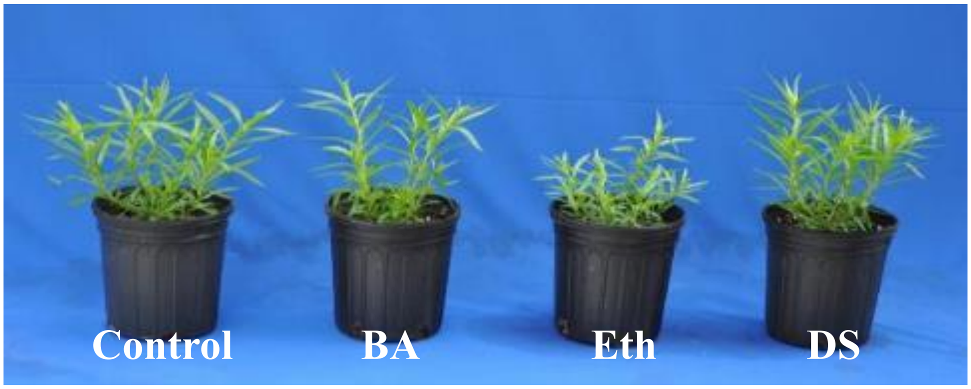
b. 2 $mg{\cdot}L^{-1}$ paclobutrazol



c. 4 $mg{\cdot}L^{-1}$ paclobutrazol

Figure 4.12. *Penstemon x mexicali* ‘Pike’s Peak Purple’ plants at 6 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench

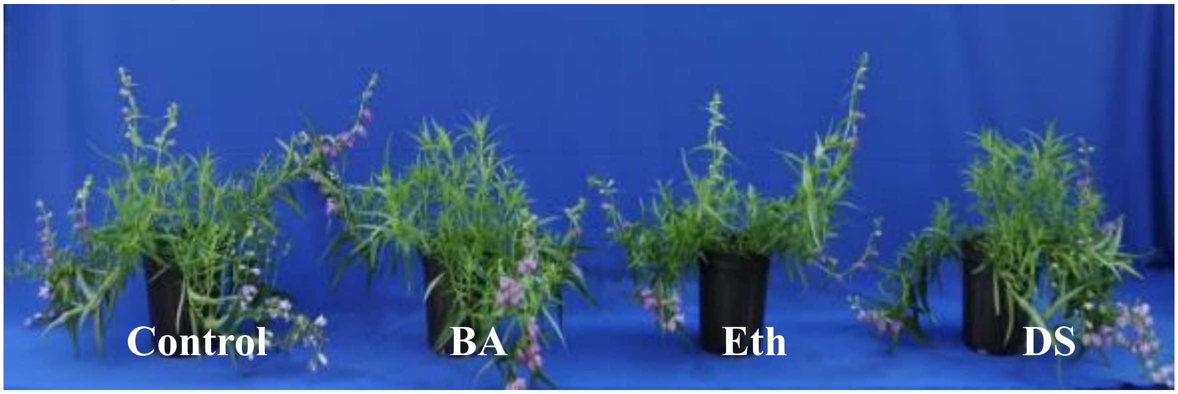


b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench

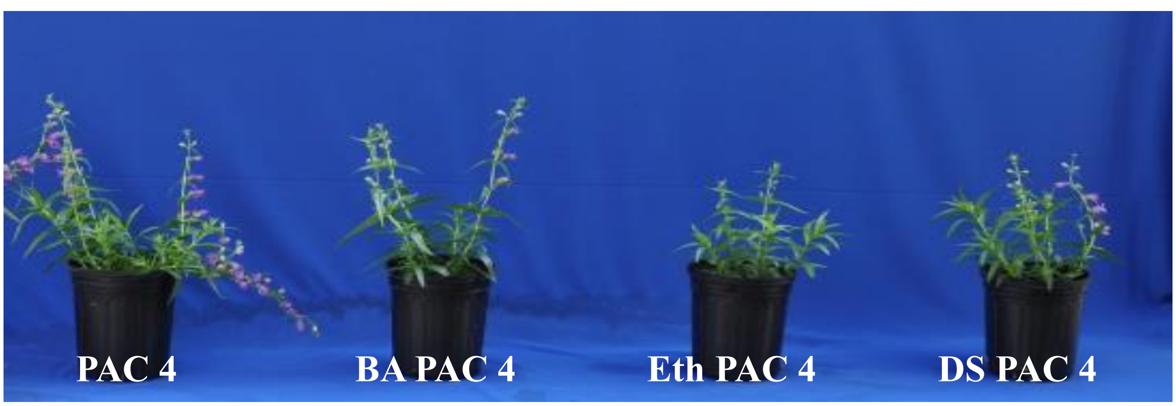
Figure 4.13. *Penstemon x mexicali* 'Pike's Peak Purple' plants at 10 weeks after the initial application of PGRs (WAIT): untreated, pinched control (Control), 600 mg·L^{-1} benzyladenine (BA) spray, 500 mg·L^{-1} ethephon (Eth) spray, 600 mg·L^{-1} dikegulac sodium (DS) spray, 2 mg·L^{-1} paclobutrazol liner drench (PAC 2), or 4 mg·L^{-1} paclobutrazol liner drench (PAC 4).

a. No paclobutrazol drench



b. 2 mg·L^{-1} paclobutrazol drench

c. 4 mg·L^{-1} paclobutrazol drench



Appendix C

Appendix

Table C.1. Plant height, average width, number of leaders, number of branches, and phytotoxicity of Penstemon x mexicali ‘Red Rocks’ at the time of the initial application of PGRs (0 WAIT) and 2 weeks after the initial application of PGRs. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot and the interaction between these two plots.

	0 weeks				2 weeks						
	Plant height	Plant width	Number of		Plant height	Plant width	Number of				
PGR rate (mg·L^{-1})	(cm)	(cm)	Leaders	Branches	(cm)	(cm)	Leaders	Branches		Phytotoxicity Rating	
Paclobutrazol											
0	3.9	11.1	1.0	9.2	5.4a[y]	10.8a	1.0	8.8		0.3b	
2	3.6	10.7	1.0	9.2	4.7b	9.9b	1.0	8.4		0.7a	
4	3.9	10.8	1.0	9.6	4.4b	9.6b	1.0	9.1		0.8a	
Paclo. rate effect	0.2815	0.2980	--[z]	0.3141	<0.0001	<0.0001	--	0.1353		<0.0001	
LSD	0.4	0.5	--	0.6	0.4	0.6	--	0.7		0.2	
Branching agent									0	2	4
0	3.9	10.7	1.0	9.3	4.8	10.0	1.0	8.8	0.0	0.6ab	0.9a
Benzyladenine 600	3.5	10.6	1.0	9.8	4.9	9.7	1.0	9.2	0.4	0.3b	0.3b
Ethephon 500	4.0	10.9	1.0	9.1	4.5	10.1	1.0	8.5	0.5	1.0a	1.0a
Dikegulac 600	3.9	11.2	1.0	9.2	5.1	10.4	1.0	8.5	0.5	0.9a	1.0a
Branching effect	0.1960	0.1941	--	0.3010	0.0704	0.2319	--	0.3196	0.1183	0.0034	<0.0001
LSD	0.5	0.5	--	0.7	0.5	0.7	--	0.8	0.5	0.4	0.3
Paclo. rate*Branching effect	0.3928	0.8602	--	0.9063	0.7472	0.8646	--	0.1488		0.0216	

[z]P-value and LSD data not available due to no difference in number of leaders between PGR groups.
[y]Means within a column followed by the same letter are not significantly different (Student’s t-test, P<0.05, n=8).

Table C.2. Plant height, average width, number of leaders, and number of branches of Penstemon x mexicali 'Pike's Peak Purple' at the time of the initial foliar PGR application (0 WAIT). Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the sub-plot and the interaction between these two plots.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)	Plant width (cm)	Number of leaders	Number of branches		
Paclobutrazol						
0	3.9	9.4	1.0	6.4		
2	4.0	9.4	1.0	6.6		
4	4.0	9.6	1.0	6.5		
Paclo. rate effect	0.7634	0.7321	--[z]	0.8487		
LSD	0.4	0.8	--	0.8		
Branching agent				0	2	4
0	4.2	9.6	1.0	6.8	5.4b[y]	7.0
Benzyladenine 600	4.0	9.9	1.0	7.1	6.5ab	6.4
Ethephon 500	4.0	9.1	1.0	5.4	6.6ab	5.9
Dikegulac 600	3.8	9.2	1.0	6.3	7.9a	6.6
Branching effect	0.2439	0.2620	--	0.1442	0.0410	0.4629
LSD	0.4	0.9	--	1.6	1.7	1.5
Paclo. rate*Branching effect	0.3209	0.2538	--	0.0442		

[z]P-value and LSD data not available due to no difference in number of leaders between PGR groups.
[y]Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, $n=8$).

Table C.3. Plant height, average width, number of leaders, number of branches, and phytotoxicity of Penstemon x mexicali 'Pike's Peak Purple' at 2 weeks after the initial foliar PGR application. Data analyzed using a split-plot design and ANOVA with different rates of paclobutrazol drenches as the main plot and branching PGRs benzyladenine, ethephon, and dikegulac sodium (dikegulac) as the subplot and the interaction between these two plots.

PGR rate ($mg \cdot L^{-1}$)	Plant height (cm)			Plant width (cm)	Number of Leaders	Number of Branches	Phytotoxicity Rating		
Paclobutrazol									
0		5.5a[z]		8.9	1.0	7.8		0.4b	
2		4.6b		8.7	1.0	7.6		0.6ab	
4		4.6b		8.5	1.0	7.6		0.7a	
Paclo. rate effect		<0.0001		0.2518	--[y]	0.6976		0.0419	
LSD		0.5		0.6	--	0.6		0.3	
Branching agent	0	2	4				0	2	4
0	6.5a	4.1b	5.5a	9.3a	1.0	7.3	0.0b	0.1b	0.5b
Benzyladenine 600	5.1bc	5.3a	4.8b	8.5b	1.0	8.1	1.5a	1.1a	1.0a
Ethephon 500	4.6c	4.4b	3.5c	7.9c	1.0	7.5	0.3b	1.0a	1.0a
Dikegulac 600	5.8ab	4.8ab	4.6b	9.0ab	1.0	7.8	0.0b	0.0b	0.3b
Branching effect	0.0016	0.0462	<0.0001	<0.0001	--	0.0751	<0.0001	<0.0001	0.0002
LSD	0.9	0.8	0.7	0.6	--	0.6	0.5	0.3	0.4
Paclo. rate*Branching effect		0.0002		0.0586	--	0.0569		0.0002	

[z]Means within a column followed by the same letter are not significantly different (Student's t-test, $P<0.05$, $n=8$).
[y]P-value and LSD data not available due to no difference in number of leaders between PGR groups.

Chapter 5 Summary: Regulation of Growth and Branching of Containerized *Penstemon x mexicali* Cultivars

Introduction

Plant growth regulators (PGRs) are chemicals that affect the growth and development of plants. These PGRs are used in the floriculture industry for the purposes of regulating plant growth by enhancing lateral branching and controlling plant height. The application of PGRs on crops like herbaceous perennials may serve as an alternative method to mechanical techniques like pinching and pruning, which are labor-intensive and less economical for growers. PGRs may benefit growers by reducing the labor costs associated with pinching and promoting higher quality, more marketable plants. Applying PGRs may result in fuller, more compact plants that are salable, manageable, and easier to handle and transport.

This research study focused on two different categories of PGRs: plant growth retardants and branching agents. Plant growth retardants function primarily in reducing growth and controlling height of plants, while branching agents act as “chemical pinchers” to enhance lateral bud growth and thus increase branching. The plant growth retardants used in this study were paclobutrazol (Piccolo10 XC, 4.0%; Fine Americas, Inc., Walnut Creek, CA), uniconazole (Concise, 0.055%; Fine Americas, Inc.), and daminozide (Dazide, 85%; Fine Americas, Inc.). The branching agents used were benzyladenine (Configure, 2%; Fine Americas, Inc.), ethephon (Collate, 21.7%; Fine Americas, Inc.), and dikegulac sodium (Augeo, 18.5%; OHP, Inc., Mainland, PA).

The herbaceous perennials used for this study were two *Penstemon x mexicali* cultivars Pike’s Peak Purple and Red Rocks. Both cultivars are upright, vigorous growers and require frequent attention to growth regulation when grown in a container. The objective of this study was to analyze the effects different PGRs and pinching practices on growth of ‘Pike’s Peak Purple’ and ‘Red Rocks.’ The goal of this research was to contribute to a production plan for producing high quality, marketable, containerized Penstemon that can be sold in the floriculture industry.

Materials and Methods

Both Penstemon cultivars arrived as unrooted cuttings from Aris Horticulture Inc. These cuttings were dipped in rooting hormone and then grown under mist until roots developed. Plant growth regulators were applied in both the liner stage and after transplant in the final container. All experiments included an untreated control. The different PGR and pinching applications used in these studies were the following:

- Benzyladenine: one application at 600 $mg \cdot L^{-1}$ in the liner stage, two applications at 600 $mg \cdot L^{-1}$ (one in the liner stage, one after transplant), applied as foliar sprays.
- Ethephon: one application at 500 $mg \cdot L^{-1}$ in the liner stage, two applications at 500 $mg \cdot L^{-1}$ (one in the liner stage, one after transplant), applied as foliar sprays.
- Dikegulac Sodium: one application at 400 or 600 $mg \cdot L^{-1}$ in the liner stage, two applications at 400 or 600 $mg \cdot L^{-1}$ (one in the liner stage, one after transplant), applied as foliar sprays.
- Paclobutrazol: one foliar spray application at 80 and 160 $mg \cdot L^{-1}$, one liner soak application at 16 $mg \cdot L^{-1}$, one liner drench application at 2, 4, 8, 12, and 16 $mg \cdot L^{-1}$.
- Uniconazole: one application at 30 and 45 $mg \cdot L^{-1}$, applied as foliar sprays.
- Daminozide: Two applications at 5000 $mg \cdot L^{-1}$ (two weeks apart), applied as foliar sprays.
- Pinches: One application during liner stage, two applications (one in the liner stage and one after transplant).

Plants were grown out in either quart or trade gallon pots. Data measurements were taken at the time of the initial PGR application and then every two weeks until the plants were considered finished and ready to harvest. Measurements included: plant height, plant average width, number of leaders, number of branches, phytotoxicity, marketability, number of flower stalks, percent of plants flowering, days to flower, and shoot dry weight.

Results and Discussion

Two applications of benzyladenine and ethephon were found to be successful at increasing branching of ‘Pike’s Peak Purple’ in the preliminary branching experiment. Application of ethephon also showed some growth control as well. Dikegulac sodium was not as effective, and so the rate was increased from 400 to 600 $mg \cdot L^{-1}$ in the future experiments to determine if increasing the rate could have more of an effect on branching. Although branching was increased by some of the PGRs, other methods of growth control were necessary in breaking apical dominance and producing a more upright plant in the container.

In order to break the apical dominance seen in the first experiment, pinching practices were utilized in the next branching agent experiment. ‘Pike’s Peak Purple’ plants were given one or two pinches. The first pinch was a hand pinch, pinching all plants back to five nodes. This first pinch occurred in the liner stage and was successful at breaking early apical dominance in the liners and promoting early lateral bud growth. The second pinch, a soft pinch removing only the terminal buds, occurred after transplant and was also effective at regulating growth while in the finished container. The branching agents, benzyladenine, ethephon, and dikegulac sodium, were applied once in the liner stage after the first pinch occurred. While these PGRs promoted some growth control and compactness, they were not as effective at increasing branches when compared to the pinched controls. One application of these PGRs may not be sufficient to have a significant impact on branching. A minimum of two applications, two weeks apart, is most likely necessary in increasing the number of branches for this specific cultivar.

Although the branching agents did not significantly increase branching in this experiment, the combination of two pinches and these branching agents produced high quality and marketable plants at 6 weeks after the PGR application. These plants were considered salable because of their compact, upright, and well-branched growth habit that filled out the container. Although these plants were not flowering, they were marketable as vegetative plants in the industry. However, once these plants began flowering, their growth habits changed and caused them to become leggy and straggly. If growers are planning to keep 'Pike's Peak Purple' in a container for a longer period of time after it has begun flowering, then further growth regulation is necessary for controlling the vigorous, wild habit of this plant.

In the first preliminary growth reduction study, foliar applications of paclobutrazol and uniconazole reduced growth of 'Pike's Peak Purple,' but this effect was not visually evident. These foliar applications reduced growth but not enough for it to have an impact on marketability. Two foliar applications of daminozide were not effective at reducing growth. Higher application rates of these PGRs may be required to regulate growth of 'Pike's Peak Purple.' The liner soak and drench applications of paclobutrazol were the most effective at reducing growth in 'Pike's Peak Purple.' However, these applications resulted in over-regulated and stunted plants. Based on the results of this study, another study specifically analyzed the effects of different rates of paclobutrazol liner drenches on controlling growth of 'Pike's Peak Purple' and 'Red Rocks.' At 8 or 12 $mg \cdot L^{-1}$, stunting was persistent in both cultivars. The 4 $mg \cdot L^{-1}$ drench rate showed slight over-regulation, but the plant was able to outgrow these PGR effects.

In the final experiment, a combination of branching and growth reduction PGRs as well as one pinching application were used on both 'Pike's Peak Purple' and 'Red Rocks.' The results varied between cultivars. Two applications of benzyladenine and one application of the 4 mg·L^{-1} paclobutrazol drench were most effective in producing upright, compact containerized 'Pike's Peak Purple' plants that were considered marketable in the industry. The most marketable 'Red Rocks' plants were produced with two applications of ethephon. 'Red Rocks' did not require any further growth control possibly because ethephon acted as both a branching agent and growth retardant in regulating its growth. Based on the results of this experiment, 'Red Rocks' is a less vigorous grower and does not require nearly as much growth control as 'Pike's Peak Purple.'

Guidelines for Growing *Penstemon x mexicali* cultivars

-Conduct your own series of trials and experiments before applying these PGRs on your own crop. Remember to include an untreated control.

-PGR applications may result in temporary phytotoxicity. Here are some common symptoms found in growing these Penstemon cultivars:

Benzyladenine: Red/purple discoloration especially along leaf margins

Ethephon: Leaf cupping

Dikegulac sodium: Leaf chlorosis

'Pike's Peak Purple'

First Recommendation: For selling as a flowering container

- Pinch once in the liner stage to break apical dominance and promote early lateral branching.
- Apply 500 mg·L^{-1} of benzyladenine twice as a foliar spray, once during the liner stage after plants have regrown some new leaf area after pinch, and again after transplant. These foliar applications should take place about two weeks apart.

- Apply 4 mg·L⁻¹ paclobutrazol as a liner drench one day prior to transplant. If liners are in a 72 cell pack, then drench plants with 10 mL of PGR solution per cell.

Second Recommendation: For selling as a vegetative container

- Pinch once in the liner stage to break apical dominance and promote early lateral branching.
- Apply 500-600 mg·L⁻¹ of a branching agent (benzyladenine, ethephon, or dikegulac sodium) once as a foliar spray during the liner stage after plants have regrown some new leaf area after pinch.
- Pinch again after transplant as plants begin to outgrow PGR treatment.

'Red Rocks'

- Pinch once in the liner stage to break apical dominance and promote early lateral branching.
- Apply 500 mg·L⁻¹ of ethephon twice as a foliar spray, once during the liner stage after plants have regrown some new leaf area after pinch, and again after transplant. These foliar applications should take place about two weeks apart.
- No additional growth retardant application is necessary.

Cost of PGR products with Examples

<u>Configure/Benzyladenine (2%)</u>: $37.50 per quart

Example:

- 600 mg·L⁻¹
- 0.5 gallons applied per 100 square feet (sq. ft.) of bench
- 1000 sq. ft. of bench area to spray
- **Total cost**: $22.50 per 1000 sq. ft. of bench area

<u>Piccolo 10XC/Paclobutrazol</u>: $800.00 per quart

Example:

- 4 mg·L^{-1} of paclobutrazol liner drench
- 72 size cell flats
- 10 mL of drench applied per cell of flat = 720 mL (24.35 fluid ounces) total per flat
- **Total cost**: $60.88 per 1000 flats
- **Total cost of PGR per flat**=$0.0609

<u>Collate/Ethephon</u>: $180.00 per gallon

Example:

- 500 mg·L^{-1}
- 1000 sq. ft. of bench area to spray
- 40.6 mL of product needed per 1000 sq. ft.
- **Total cost:** $1.93 per 1000 sq. ft. of bench area