Effects of Growing Season, Application Timing, and Substrate Drench Applications of Paclobutrazol as Compared to Daminozide Standards on Growth and Flowering of Gerbera Daisy 'Bright Red with Light Eye'

by

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Abstract

Gerbera daisy (*Gerbera jamesonii* Hook. f.) is a popular pot plant with showy flowers, commonly marketing in spring. However, plants grown under greenhouse conditions can stretch or grow too large for containers. Plant growth retardants (PGRs) can be used to control plant growth and flowering, enhance plant appearance and uniformity, and minimize transport stress. Two studies were conducted to determine the optimal substrate drench concentration of paclobutrazol (Bonzi) as compared to daminozide (B-Nine) foliar spray standards in different seasons and at different application stages for plant size control and improved market quality of gerbera daisy 'Bright Red with Light Eye'.

In the first study, plants in 12.7cm (5 in) pots were treated with 0, 1, 2, 3, or 4 ppm paclobutrazol substrate drenches or a 2500 ppm daminozide foliar spray at two application stages for a fall 2015 or spring 2016 finish. When the majority of pots had roots at the bottom of the substrate, plants were treated with PGRs as stage 1, and stage 2 was applied 2 weeks later. A consumer preference survey was conducted to assess consumer-purchasing preference based on quality ratings assigned when plants had 2 or 3 open flowers. Plant size index, foliage height, peduncle length, flower diameter, and quality rating decreased linearly while days to first flower increased quadratically with increasing paclobutrazol concentration, regardless of application stage or season. Foliage height, plant size index, and peduncle length for fall were greater than for spring. Days to first flower, flower and bud counts, and quality ratings were greater for the spring than fall, but these differences were small and not likely of horticultural significance.

Likewise, differences between stages were only found for foliage height and these were small. Plants that received 0 or 1 ppm paclobutrazol were often larger and those that received 4 ppm paclobutrazol were often smaller than those that received daminozide. Based on quality rating and survey results, 1 or 2 ppm paclobutrazol drench produced the most marketable plants in fall, and 0, 1, 2, or 3 ppm produced the most marketable plants in spring. The standard daminozide concentration produced plants too small for the highest quality rating or consumer preference.

In the second study conducted in summer 2016, plants in 12.7cm (5 in) pots were treated with 0, 1.5, or 3 ppm paclobutrazol substrate drenches or a 2500 ppm daminozide foliar spray at weekly intervals from 2 to 6 weeks after transplanting (WAT). A daminozide standard was applied at 2500 ppm 2 WAT and again 10 days later. Foliage height, plant size index, flower diameter, peduncle length, and quality rating decreased while days to first open flower (DTF) increased linearly or quadratically with increasing paclobutrazol concentration regardless of application timing. Foliage height, size index, flower diameter, peduncle length, and quality rating of plants receiving daminozide weekly were smaller than or not different from 0 ppm paclobutrazol, but larger than those receiving 1.5 or 3 ppm. Peduncle length and DTF decreased linearly with increasing WAT regardless of growth retardant treatment. Foliage height, size index, and peduncle length of plants receiving daminozide at 2 weeks only were larger than those receiving 1.5 or 3 ppm paclobutrazol, but not different from those receiving 0 or 1.5 ppm. Flower diameter and DTF of plants receiving daminozide at 2 weeks were not different from paclobutrazol. Quality rating was higher for plants receiving daminozide at 2 weeks than those receiving 1.5 or 3 ppm paclobutrazol. Differences in paclobutrazol treatments and daminozide applied twice were similar to those of daminozide applied at 2 weeks, and there were no differences in daminozide applied at 2 weeks and daminozide applied twice. Treatments did not affect time to flower senescence. Based on quality ratings, no growth retardant or daminozide applied once at 2500 ppm anytime from 2 to 6 WAT produced the most marketable plants. However, later PGR application resulted in earlier flowering and greater reductions in peduncle length.

Across the two studies, increasing concentrations of paclobutrazol drenches reduced plant size and had a negligible negative impact on DTF or flower diameter. However, PGR treatments that resulted in the highest quality ratings and consumer preference were different depending on season. Plant quality was improved by paclobutrazol drenches at the lower concentrations for a fall finish and to a lesser extent for a spring finish, though the effective concentration range included 0 ppm. However, paclobutrazol drenches did not improve plant quality in the summer. In the first study, PGR treatments were applied in early October for a fall finish and in early March for a spring finish while in the second study, treatment were applied in April and May. Warmer temperatures and higher light intensities may have resulted in more compact plants in the summer than in the spring and fall, thus reducing the effectiveness PGR treatments on plant quality in the summer.

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List of Abbreviations

SD	Short-day
LD	Long-day
h	Hours
cm	Centimeter
in	Inch
PGR	Plant Growth Retardant
ppm	Parts per Million
L*	Lightness
mg	Milligram
a.i.	Active Ingredient
oz	Ounce
g	Gram
GA	Gibberellin
C	Degree Celsius
F	Degree Fahrenheit
s	Second
Min	Minute
N	Nitrogen
P	Phosphorus
K	Potassium

qt	Quart
ft	Foot
RH	Relative Humidity
SI	Size Index
DTF	Days to First Flower
AIC	Akaike Information Criterion
WAT	Weeks after Transplant

CHAPTER I

Introduction

During commercial gerbera daisy production, foliage too large or flower stems too long for the container size are common problems. Plant growth retardants (PGR) control plant growth by inhibit gibberellin biosynthesis (Latimer, 2004). PGR applications shorten leaf petioles and flower stem lengths. Leaves are darker and more attractive. PGRs also permit closer plant spacing on greenhousae benches, thus increasing production per unit area, facilitating easier handling, and reducing shipping damage (Rogers and Tjia, 1990).

Daminozide is an older, but widely used PGR in the greenhouse industry. In the United States, daminozide makes up 54% of the total weight of growth regulators used in greenhouses (Norcini et al., 1996). Paclobutrazol is very active compared with non-triazole plant growth retardants. It is an effective plant growth retardant (PGR) for controlling plant size in many species, like gerbera daisy (Bekheta et al., 2008), oriented knight's-spur (*Consolida orientalis* Schrödinger) (Mansuroglu et al., 2009), scented bouvardia (*Bouvardia humboldtii* Hend. & Andr. Hend.) (Wilkinson and Richards, 1987), and chrysanthemums (*Chrysanthemun ×morifolium* Ramat.) (McDaniel, 1983). It was reported to inhibit stem elongation in sunflower (*Helianthus annuus* L.) (Wample and Culver, 1983) and soybean (*Glycine max* (L.) Merr.) (Sankhla et al., 1985), darken leaves in oriented knight's-spur (Mansuroglu et al., 2009), reduce peduncle length in gerbera daisy (Armitage, 1984; Bekheta et al., 2008), panicle length in 'Dubonnet' butterfly-bush (B*uddleia davidii* Franch.) (Ruter, 1992), and pedicel length in oriental knight's-spur (Mansuroglu et al., 2009). Paclobutrazol also delayed flowering (Bañón et al., 2002; Singh et al., 2016; Thompson et al., 2005) or enhanced flowering (Bailey et al., 1986; Karagüzel, 1999; Stamps and Henny, 1986), increased flower number (Bekheta et al., 2008; Mansuroglu et al., 2009; Singh et al., 2016; Wilkinson and Richards, 1987) or decreased flower number (Bañón et al., 2002, Ruter, 1992).

Paclobutrazol was recommended at 2.5–5 ppm as a foliar spray or at 0.25–0.5 ppm as a substrate drench for gerbera daisy, but no further details about application were given (GoldSmith Seed, 2016). Pot plant gerberas are commonly market throughout the spring, summer, and into the fall (Hamrick, 2003). However, sowing seeds in summer for finished plants in winter could make gerbera daisy an alternative holiday crop. The objective of first study was to determine the effects of paclobutrazol substrate drenches compared with a daminozide foliar spray standard applied at two application stages on growth, flowering, and marketable quality rating of ‘Bright Red with Light Eye’ gerbera daisy for a fall and spring finish time.

Different application times of PGRs were reported that lead to different impacts on growth and flowering (Armitage, 1984; Barrett et al., 1995; Gilbertz, 1992). The objective of second study was to examine the effects of application timing and substrate drench applications of paclobutrazol as compared to daminozide standards on growth and flowering of gerbera daisy.

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CHAPTER II

Literature Review

Gerbera Daisy

Gerbera daisy (*Gerbera jamesonii* Bolus ex Hook. f.) is one of the most popular flowers in the world, recognized for its bold, clean flowers (Rogers and Tjia, 1990). It is a versatile crop used as a bedding plant, cut flower, or pot plant. In 1890, Captain Robert Jameson discovered the wild species of gerbera daisy in the Transvaal area of South Africa. The wild species and early cultivars were larger plants than today's pot plant cultivars with longer flower stems used as cut flowers. Gerbera daisies have been in commercial production in North America since the early 1920s. In the early 1980s, Sakata Seed Company of Japan first introduced 'Happipot', a seed-propagated selection of gerbera daisy that had short flower stems and a plant size suitable as a pot crop. Gerbera daisy grown as a pot crop are commonly marketed throughout the spring, summer, and into the fall (Hamrick, 2003). Its wide variety of colors and daisy flowers grown in a range of pot sizes are valued by consumers (Briggs-Macha, 2015).

Gerbera daisy is a facultative short-day (SD) photoperiod plant (Currey and Lopez, 2011). SD photoperiod increased cut flower gerbera productivity compared with plants under long-day (LD) photoperiod in summer-fall (Lin and French, 1985). Day length of 8–10h is optimal for all gerbera daisy cultivars. Plants produced more flowers under SD than under LD (Leffring, 1981).

Dwarf gerbera daisy cultivars with short flower stems used are selected to be grown as pot plants, usually in 12.7–15.2 cm (5–6 in) pots. Most gerbera daisies grown as pot plants are started by sowing seed in plug flats (Hamrick, 2003). Gerbera daisy seeds (212–282 per gram) are expensive and sensitive to environment conditions during germination. Seeds are sown in plug flats with 84–200 cells per flat and are covered with coarse vermiculite. Once seedlings developed (only one) their first true leaves, usually 28–38 days after sowing, ancymidol (A-Rest), daminozide (B-Nine), or paclobutrazol (Bonzi) can be used to control plant size. Thirty five to 45 days are required from sowing seed to transplantable seedlings. Most gerbera daisy seedlings are transplanted into 10.2–15.2 cm (4–6 in) pots for finishing. Plants are spaced before leaves cover the crowns of adjacent plants at 4–6 weeks after transplanting. During high-light times of the year, plants are salable 8–10 weeks after transplanting. However, plants transplanted between October and January may require an additional 3–4 weeks to reach salability.

Plug-grow seedlings suitable for transplanting cost approximately $0.75 each in 1990 (Rogers and Tjia, 1990). Total production cost for a 10.2 cm (4 in) pot was $1.44–$1.67, a 12.7 cm (5 in) pot was $1.76–$2.24, and a 15.2 cm (6 in) was $2.37–$2.98 assuming 8–12 weeks from transplanting to sale. In Floriculture Crops 2015 summary (U.S. Department of Agriculture, 2016), gerbera daisy cut flowers were sold 106,680,000 spikes at 30.4 cents per spike and the total value of all sales made was $32,423,000 at wholesale. However, no information provided for summary of pot gerbera daisy sales. Foliage too large or flower stems too long for the container size are common problems for gerbera daisy. Plant growth retardants (PGRs) can be applied to suppress plant size and flower stem elongation (Hamrick, 2003). Daminozide is recommended as a foliar spray at 1,000–2,500 ppm, once or twice, at an interval of 9–10 days with the first application made 12–14 days after transplanting. Ancymidol was effective either as a spray or as a substrate drench. A foliar spray at 33–66 ppm or substrate drenches at 0.125–0.25 mg a.i. per 15.2 cm (6 in) pot were recommended (Rogers and Tjia, 1990). Application of a PGR once flower buds are visible (greater than 1 cm (0.4 in) diameter) may delay flowering and reduce flower size (PanAmerican, 2015; GoldSmith Seed, 2016). Paclobutrazol was also recommended at 2.5–5.0 ppm (0.078–0.625 mg a.i per 15.2 cm (6 in) pot or larger pot) as a foliar spray or at 0.25–0.5 ppm as a substrate drench.

Plant Growth Retardants

Container plants should be no taller than twice the diameter of their pot to maintain a pleasing aesthetic ratio (Beattie, 1982). Many floricultural species are naturally too large for production in standard-sized pots. When these plants were grown under greenhouse conditions, they can grow excessively tall and leggy in appearance, thus decreasing the value of the crop and increasing shipping costs (Amling et al., 2005; Kessler and Keever, 2007 and 2008).

Applications of PGRs provide several benefits to plants (Rogers and Tjia, 1990). PGRs shorten leaf petioles and flower stem lengths, making plants more bushy and compact. Leaves are darker and more attractive. PGRs permit closer plant spacing, thus increasing production per unit area, facilitating easier handling and reducing shipping damage.

PGRs are synthetic compounds that suppress stem elongation and generally increase the green color of leaves. Most PGRs inhibit gibberellin biosynthesis, which is naturally-occurring plant hormones that promote cell elongation (Latimer, 2004), by limiting kaurene synthesis and oxidation (Gianfagna, 1995).

Commercial PGRs include several older compounds that were introduced to floriculture in the 1960s and 1970s like daminozide, chlormequat chloride (Cycocel) and ancymidol. These products are still commonly used in the industry. In the 1980s, a new class of compounds was introduced, the triazoles that included paclobutrazol and uniconazole (Sumagic). These products are much more potent than the older chemistries. Different PGR chemicals have different biochemical modes of action. Daminozide inhibits plant growth by inhibiting translocation or promoting degradation of gibberellin. Sachs et al. (1960) observed that daminozide retarded stem elongation by completely inhibiting subapical meristematic activity in the stem. Chlormequat chloride contains a quaternary ammonium group that inhibits the step from geranylgeranyl pyrophosphate to ent-kaurene in gibberellin biosynthesis. Ancymidol contains a pyrimidine group that inhibits ent-kaurene oxidation by blocking the action of monooxygenase enzyme. Triazoles, inhibit one or more cytochrome oxidase enzymes that are important in sterol and gibberellin biosynthesis (Rademacher, 1991).

A daminozide foliar spray was effective on controlling plant growth on chrysanthemum (*Chrysanthemum morifolium* Ramat.) (Gianfagna, 1995). Ancymidol can also be used as a foliar spray or a substrate drench on chrysanthemum, but may delay flowering. Chlormequat chloride is widely used for poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) height control because it costs less than ancymidol. In Easter lily, ancymidol is very effective for reducing shoot height.

PGRs were reported to either increase (Davis et al., 1985; Wang and Faust, 1986; Watson, 1996), decreased (Cathey and Marth, 1960; Early and Martin, 1988; Ruter, 1994), or have little effect on root growth (Gianfagna, 1995), but always to increase root: shoot ratio (Ruter, 1994).

Stuart (1961) demonstrated that PGR application suppressed vegetative growth and prompted flower bud initiation in *Rhododendron* indicating that application of PGRs may affect the flowering process. The flowering process may remain unaltered, be accelerated, or be delayed by PGR application (Cathey, 1964). The sizes of petals and pedicles were reduced after applying chlormequat chloride drenches to hydrangea and geranium (Cathey and Stuart, 1961). Plants treated with PGRs were more compact and had deeper foliage color (Wittwer and Tolbert, 1960). Plants were less susceptible to wilting after treatment with PGRs like in chrysanthemum (Lindstrom and Tolbert, 1960).

Coreopsis rosea Nutt. 'American Dream', or pink coreopsis, was treated with foliar sprays of daminozide at 2500–7,500 ppm, flurprimidol (Cutless) at 25–150 ppm, uniconazole at 10–40 ppm, or paclobutrazol at 25–100 ppm (Burnett et al., 2000). At first flower, daminozide, flurprimidol, and uniconazole applications suppressed plant growth by 13–31%. Compared to the control group, PGR applications increased plant quality ratings by 52–67%. Plants treated with PGRs also had greater compactness, more branches, darker green foliage, and more flowers. PGR applications had no effect on time to first flower or to a marketable stage. Paclobutrazol did not control growth or affect flowering of pink coreopsis.

Paclobutrazol

Paclobutrazol is an inhibitor of gibberellin biosynthesis through inhibiting the oxidation of ent-kaurene to kauronic acid, which in turn led to inhibited gibberellin biosynthesis (Al-Khassawneh et al., 2006). It has exhibited little or no phloem mobility (Shanks, 1980).

Paclobutrazol is very active compared with non-triazole plant growth retardants. It was more effective applied as a foliar spray in controlling pot chrysanthemum 'Bright Golden Anne' stem extension than drenches of chlorphonium chloride (Phosfon/Phosfleur), or foliar sprays of daminozide or piproctanyl bromide (Alden/Stemtrol) on a weight basis (Menhenett, 1984). Paclobutrazol foliar sprays were also more effective than ancymidol foliar sprays on height control of pot chrysanthemum, while drench applications of paclobutrzol and ancymidol had similar effects. However, Davis et al. (1986) reported that paclobutrazol drenches were more effective in height control of poinsettia than ancymidol, but less effective than ancymidol drenches in height control of pot *Tulipa hybrida* (Menhenett and Hanks, 1982).

Paclobutrazol reduced stem elongation in many species. Inhibition of stem elongation was accompanied by reduced internode length in sunflower (Wample and Culver, 1983) and shoot weight in soybean (Sankhla et al., 1985).

Paclobutrazol can be applied either as a foliar spray or as a soil drench. As a foliar spray, stem and shoot uptake are particularly important. Shoot tissues vary in their ability to take up the active ingredient (Barrett and Bartuska, 1982). Container-grown ‘Sprite Bean’ and ‘Bright Golden Anne’ chrysanthemum plants received paclobutrazol drench applications at 0.125 mg a.i. per pot or spray applications at 75 ppm or 150 ppm to whole shoots, mature leaves, or stems. In all cases, paclobutrazol reduced stem elongation, but retardation was greater with applications to the stems or whole shoots than to the leaves.

Gerbera daisies planted in 30 cm (12 in) diameter clay pots received paclobutrazol sprays at 0, 25, 50 or 100 ppm (Bekheta et al., 2008). All paclobutrazol rates reduced plant height and increased number of leaves per plant and leaf fresh and dry weight. There were also decreases in pedicle lengths, with the greatest reduction at 100 ppm. Paclobutrazol at 50–100 ppm increased peduncle (author reported pedicle) diameter. All rates increased flower numbers per plant and flower water content.

Oriental knight's-spur (*Consolida orientalis*) treated with paclobutrazol foliar spray at 0, 125, 250 or 500 ppm when 5% of plants had elongated first internodes (Mansuroglu et al., 2009). All paclobutrazol applications reduced plant height, length and internode length of inflorescence, pedicel length and the number of secondary inflorescence. Paclobutrazol spray at

250 ppm increased flower number on the main inflorescences and spray at 500 ppm increased the stem diameter and flower number on secondary inflorescences. Treatments also decreased the lightness (L*) and color saturation (chroma) values of leaves and lightness (L*) of flowers, so that plants treated by paclobutrazol had darker leaves and deeper violet flower. However, paclobutrazol had no effect on the time from sowing to flowering.

During spring, pot carnation (*Dianthus caryophyllus* L. var. tergestinus (Rchb.) Tanfani) received paclobutrazol drenches at 0.45–1.12 mg a.i. per pot or sprays at 0.16–0.65 mg a.i. per pot and, during winter, paclobutrazol was applied as drenches at 0.125–0.45 mg a.i. per pot (Bañón et al., 2002). In general, paclobutrazol controlled plant growth and improved commercial quality. In spring, drench applications were more effective than sprays in reducing plant growth. Spring-grown plants produced more flower buds than winter-grown counterparts. In winter, a drench of 0.25 mg a.i. paclobutrazol per plant produced better quality plants than the control. All spray and drench rates greater than 0.45 mg a.i. darkened leaf color slightly. Days from potting to the end of cultivation was longer in winter-grown than in spring-grown plants for climatological reasons. In addition, paclobutrazol treatments changed flower color from red to more purple on plants grown in winter.

Ornamental pepper ‘Pitanga’ (*Capsicum chinense* Jacq.) received a foliar spray of paclobutrazol at 0, 30, 60, 90, 120, or 150 ppm, or substrate drenches at 0, 5, 10, 15, 30, or 60 ppm (Grossi et al., 2005). All rates of paclobutrazol sprays and drenches decreased plant height, plant diameter, and plant dry mass, and increased leaf chlorophyll content. High rate of paclobutrazol drench at 30 ppm or 60 ppm resulted in severe retardation.

McDaniel (1983) treated chrysanthemums in 15 cm (6 in) pots with single or two paclobutrazol foliar sprays at 0–5.0 mg a.i. per plant, the first application was made one week following the pinch and the second application following removal of lateral bud. Also, drench rates at 0–0.75 mg a.i. per plant were applied. Plants were treated under both summer and winter conditions. The results from the two seasons were similar. All foliar spray significantly reduced plants height compared with control plants. And high rates of soil drench applications excessively reduced the plant growth. Compared to foliar spray, substrate drenches inhibited height extension to a larger extent. Dry weight was reduced in all cultivars. However, paclobutrazol applications did not reduce flower number or delay time to flower.

Plants of *Bouvardia humboldtii* Hend. & Andr.Hend. received either foliar sprays or substrate drenches of paclobutrazol (Wilkinson and Richards, 1987). The spray treatments were three applications at 250 ppm, two applications at 500 ppm, or one application at 1,000 ppm. Drench application rates were at 0–4.0 mg a.i. per pot. All paclobutrazol treatments reduced plant height and dry weight. Reductions in root growth were more than shoot growth. This indicated that the plant root system was sensitive to paclobutrazol application. Also, foliar spray runoff onto the pine bark media would be absorbed by root in small, but highly concentrated doses of paclobutrazol. Paclobutrazol treated plants also showed a substantial increase in flower numbers. Spray treatments at 250 ppm or 500 ppm or a drench treatment at 2.0 mg a.i. per pot were the most effective, with flower numbers about 35% greater than control plants. The increase in flower numbers may have resulted from paclobutrazol diverting assimilates into flower development because of reduced demand by the roots, or paclobutrazol may have reduced gibberellin biosynthesis in plants that promoted flower formation.

Paclobutrazol drench formulation had effects on plant growth and flowering. Paclobutrazol drenches at 0–40 mg a.i. per pot were applied as a granular formulation or as a single 100-ml liquid drench to butterfly-bush (Ruter, 1992). Granular and liquid applications reduced shoot dry weight, root dry weight, and plant biomass. Granular application also reduced panicle count per plant, but liquid application did not. However, panicle length was reduced by 66% by granular application, but only 40% by liquid application compared with control group. The number of panicles with open florets was not affected by formulation and rate of application.

Gibberellin biosynthesis inhibitors have effects on particular transitions during flower development (Pharis and King, 1985). Kim et al. (1989) applied uniconazole at 0.1 mg/plant to Zinnia 'Red Sun'. This resulted in a 4-day delay in the transition to the reproductive stage, and production of single flowers with ray petals converted to tubular petals.

Watsonias 'Shrimp Pink' plants were drenched with 5, 10 or 20 mg paclobutrazol delivered in 100 ml (3.4 oz) distilled water when the second leaf reached 15 cm (5.9 in) in length (Thompson et al., 2005). Paclobutrazol reduced foliage height to 49% ,63% or 75% of controls with increasing concentrations. However, leaf number was not affected by drench applications. Paclobutrazol also decreased the inflorescence heights by 28%, 62% or 83% of controls with increasing concentrations. The highest concentration resulted in excessive dwarfing of inflorescences relative to foliage height. Also, times to first flower increased with increasing concentrations. The number of flower per spike were also reduced by drench applications.

Geranium (*Pelargonium ×hortorum* L.H. Bailey) was treated with a paclobutrazol drench at 0, 10 or 20 ppm 25 days after pinching (Singh et al., 2016). Plant height and spread decreased and number of shoots per plant increased with increasing paclobutrazol concentration. Flower bud formation and time to first flower were delayed by paclobutrazol. Paclobutrazol drenches decreased inflorescence diameter and increased the number of inflorescence per plant. Palobutrazol application also increased pot presentability. The number of opened inflorescences at one time per plant was increased by increasing rate and flowering duration time was reduced by drench application.

Contrary to previous findings, time to flower was sometimes decreased by paclobutrazol applications. Paclobutrazol drenches at 0–50 mg a.i. per pot and foliar sprays at 0–1,000 ppm were applied to *Bougainvillea spectabilis* var. *virescens* (Choisy) J.A.Schmidt plants grown in 18 cm (7.1 in) pots under long and short natural photoperiods (Karagüzel, 1999). In all treatments, time from application to flower decreased slightly under long photoperiods, but this decrease did not occur under short photoperiods. Numbers of flowers per plant and shoot length decreased, while shoot number increased. Floral initiation was also stimulated by paclobutrazol application on *Episcia cupreata* (Stamps and Henny, 1986) and *Hydrangea macrophylla* (Bailey et al. 1986).

Paclobutrazol has exhibited senescence-delaying properties. Paclobutrazol at 0–1,000 ppm or chlormequat chloride at 0–1,000 ppm was applied to strawberries (*Fragaria* ×*ananassa* Duch.). Paclobutrazol decreased yield by delaying fruit ripening (McArthur and Eaton, 1988). Paclobutrazol slightly increased leaf number and delayed leaf senescence. Paclobutrazol reduced the activities of protease and RNase, delayed chlorophyll loss and caused a senescence-linked rise in lipid peroxidation in intact senescing soybean leaves (Davis et al., 1985; Sankhla et al., 1985; Upadhyaya et al., 1985)

Paclobutrazol also delayed floral senescence. Ecker et al. (1992) applied paclobutrazol as substrate drench at 0–2.5 mg a.i. per pot to two cultivars of *Matthiola incana* (L.) W.T. Aiton subsp. *pulchella* (Conti) Greuter & Burdet, 'Midget- Red' that is an early flowering and short cultivar and 'Lavender' that is a late flowering and medium-height cultivar. Both cultivars were treated with paclobutrazol 20 days after potting. Paclobutrazol substrate drenches delayed flowering in ‘Lavender’ by 23 days, but not in ‘Midget-Red’ because treatments were applied after flower buds appeared. Inflorescence lengths of both cultivars were reduced by paclobutrazol treatments. The percentage of senesced flowers in ‘Midget-Red’ recorded 30 days after the onset of flowering decreased from 67% to 0% with increasing rates of paclobutrazol. Similar results were observed in ‘Lavender’.

Timing of paclobutrazol applications affects plant growth. Plants of *Caladium ×hortulanum* Birdsey ‘Aaron’, ‘White Christmas’, and ‘Carolyn Wharton’ received paclobutrazol drench treatments (Barrett et al., 1995). Drenches at 2.0 mg a.i. per pot did not affect height of *Caladium ×hortulanum* Birdsey ‘Aaron’ or ‘White Christmas’ when applied 1 week after planting, but did result in shorter plants when applied 3 weeks after planting. The amount of roots present to take up paclobutrazol drenches may have led to differences in timing of application.

Gilbertz (1992) applied paclobutrazol sprays at 30–60 ppm to plants of *Dendranthema ×grandiflorum* (Ramat.) Kitam. at 0, 2 or 4 weeks after pinching. The earlier applications resulted in shorter plants, but plants took longer to flower. Flower size was minimally affected by the treatments.

Ghadage et al. (2015) applied paclobutrazol treatments to acid lime (*Citrus aurantifolia* L.) to determine the effects on flowering and plant yield. Paclobutrazol was applied at 0–4.5 g a.i. per plant on July 15, July 31 or Aug. 15. Paclobutrazol applied on Aug. 15 resulted in the highest number of flower per shoots, the highest fruit set, the lowest fruit drop, the highest number of fruits per shoot, the highest fruit yield per plant, and the highest fruit yield per hectare.

Daminozide

Daminozide is an older, but widely used PGR in the greenhouse industry. In the United States, daminozide makes up 54% of the total weight of growth regulators used in greenhouses (Norcini et al., 1996). Daminozide has a unique chemical structure from other PGRs (Gent and McAvoy, 2000). There are no analogous compounds in commercial use as a PGR. Daminozide inhibits gibberellins translocation or promotes their degradation (Rademacher, 1991). It inhibits the processes that oxidizes GA12-aldehyde into other gibberellins, specifically inhibiting the process where GA_{20}, which is an inactive form, is converted to GA_1 (Brown et al., 1997).

Daminozide is labeled for use on bedding plants and herbaceous perennials under greenhouse and nursery conditions (OHP, Inc., 2011). Generally, daminozide is not phytotoxic. It has relatively short effectiveness times, so it seldom results in excess growth suppression of treated plants. Due to the short effectiveness time however, daminozide may need to be applied more frequently to maintain size control over vigorous crops. Daminozide is subject to degradation by soil microorganisms; the half-life of daminozide in soil is approximately 21 days (U.S. Environmental Protection Agency, 1986). Therefore, daminozide is only effective as a foliar spray. Daminozide is also slower to exhibit an effect on a crops than trizole PGRs. Generally, foliar sprays of 5,000 ppm are applied every 7–14 days as necessary (Latimer, 2001). Vigorous cultivars grown outdoors may need increased application frequency.

Poinsettia ‘Freedom Red’, ‘Success Red’, and ‘Winter Rose Dark Red’ were treated with 14 different tank mixes combining daminozide and chlormequat chloride (Lewis et al., 2004). Several treatments reduced stem elongation in all three cultivars. Bract area of poinsettia ‘Freedom Red’ and canopy bract diameter of ‘Winter Rose Dark Red’ decreased with increasing concentration of daminozide and chlormequat chloride. However, bract area of ‘Success Red’ was only affected by daminozide. Time to flower was not delayed by PGRs.

Armitage et al. (1984) applied ancymidol at 200 ppm and daminozide at 4,000 ppm to gerbera daisy (*Gerbera jamesonii*) as foliar sprays 5–8 weeks after transplanting. Treatments were repeated 10 days later. Plants had reduced peduncle length, total height and vegetative height when ancymidol was applied at 6 or 7 weeks after transplant compared with other treatments. Daminozide treated plants had visible buds earlier than those treated with ancymidol. Plants treated with daminozide 6 weeks after transplant reached visible buds earlier than the control. Daminozide more effectively controlled peduncle length, total height and vegetative growth when applied 8 weeks after transplant. Leaf number and flower diameter were not affected by PGR treatments.

Few studies have been conducted to examine the effects of PGRs on plant size and flowering of gerbera daisy and they are dated (Armitage et al. 1984; Bekheta et al. 2008). In the meantime, new gerbera daisy cultivars have been introduced and adopted by the greenhouse industry for pot plant culture with different characteristics for older cultivars. Therefore, the objective of this work is to examine the effects of production season, plant stage of development and substrate drench applications of paclobutrazol as compared to a daminozide standard on growth and flowering of gerbera daisy.

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CHAPTER III

Effects of Growing Season, Plant Stage of Development, and Substrate Drench Applications of Paclobutrazol as Compared to a Daminozide Standard on Growth and Flowering of Gerbera Daisy 'Bright Red with Light Eye'[1]

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Abstract

The objective of this work was to determine the optimal substrate drench concentration of paclobutrazol (Bonzi) as compared to a daminozide (B-Nine) foliar spray standard in two finishing seasons and at two application stages for plant size control and improved market quality of gerbera daisy (*Gerbera jamesonii* Hook. f.) 'Bright Red with Light Eye'. Plants in 12.7cm (5 in) pots were treated with 0, 1, 2, 3, or 4 ppm paclobutrazol substrate drenches or a 2500 ppm daminozide foliar spray at two application stages for a fall or spring finish. Stage 1 was when the majority of pots had roots at the bottom of the substrate and stage 2 was 2 weeks later. A consumer preference survey was conducted to assess consumer-purchasing preference based on quality ratings assigned when plants had 2 or 3 open flowers. Plant size index, foliage height, peduncle length, flower diameter, and quality rating decreased linearly while days to first flower increased quadratically with increasing paclobutrazol concentration, regardless of

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application stage or season. Foliage height, plant size index, and peduncle length for fall were greater than for spring. Days to first flower, flower and bud counts, and quality ratings were greater for the spring than fall, but these differences were small and not likely of horticultural significance. Likewise, differences between stages were only found for foliage height and these were small. Plants that received 0 or 1 ppm paclobutrazol were often larger and those that received 4 ppm paclobutrazol were often smaller than those that received daminozide. Based on quality rating and survey results, 1 or 2 ppm paclobutrazol drench produced the most marketable plants in fall, and 0, 1, 2, or 3 ppm produced the most marketable plants in spring. The standard daminozide rate produced plants too small for the highest quality rating or consumer preference.

Index words: plant growth retardant, B-Nine, Bonzi, greenhouse production.

Chemicals used in this study; B-Nine (daminozide) [butanedioic acid mono (2,2-dimethylhydrazide)] and Bonzi (paclobutrazol) [(±)-(R*,R*)-β-[(4-Chlorophenyl)methyl]-α-(1,1-dimethylethyl)-lH-1,2,4-triazole-1-ethanol].

Species used in this study: Gerbera daisy (*Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye').

Significance to the Horticulture Industry

Gerbera daisy is a popular pot plant with showy flowers, commonly marketing in spring. However, plants grown under greenhouse conditions can stretch or grow too large for containers. Plant growth retardants (PGRs) can be used to control plant growth. Daminozide foliar spray is the industry standard practice in gerbera daisy production. Paclobutrazol was reported more effective and longer lasting than daminozide for many greenhouse crops, and may be more effective applied as a substrate drench than a foliar spray. In this study, plants were treated with 0, 1, 2, 3, or 4 ppm paclobutrazol substrate drenches or a 2500 ppm daminozide foliar spray at two application stages for fall and spring finishing. Increasing rates of paclobutrazol drench treatment effectively controlled plant growth by decreasing foliage height, plant size index, and peduncle length. PGR applications also delayed flowering, and decreased flower diameter and flower and bud counts, but these differences were small and not considered of practical importance. Plant were larger in the fall than the spring, but there were only small differences in foliage height between stages. Paclobutrazol drench treatment improved plant market quality. A 1 or 2 ppm paclobutrazol drench applied in 12.7cm (5 in) pots resulted in optimal consumer's preference of gerbera daisy in fall, while in spring, 0, 1, 2, or 3 ppm paclobutrazol drench resulted in the same consumer preference. The industry standard practice of 2500 ppm daminozide rate was excessive for high consumer preference of this cultivar. Gerbera daisies were of excellent quality with a fall finishing and has potential in the floral market for the holiday season.

Introduction

Gerbera daisy is a versatile crop used as a bedding plant, cut flower, or pot plant. Grown as a pot crop, they are commonly marketed throughout the spring, summer, and into the fall (Hamrick 2003). The wide variety of colors and daisy flowers produced in a range of pot sizes are valued by consumers (Briggs-Macha 2015). In greenhouse production, foliage too large or flower stems too long for the container size are common problems for gerbera daisies. Plant growth retardants (PGRs) can be applied to reduce plant size and flower stem length.

Daminozide is an older, but widely used PGR in the greenhouse industry. It has a relatively short activity and seldom results in excess growth suppression. Daminozide was recommended for gerbera daisy as a foliar spray at 1000–2500 ppm, once or twice at 9–10 day interval with the first application made 12–14 days after transplanting (Hamrick 2003).

Armitage et al. (1984) applied daminozide at 4000 ppm to gerbera daisy as a foliar spray at 5–8 weeks after transplanting, and again 10 days later. Plants treated 6 weeks after transplanting reached visible buds earlier than the control. Daminozide more effectively controlled peduncle length, total height, and vegetative growth when applied 8 weeks after transplant. Leaf number and flower diameter were not affected by PGR treatments.

Paclobutrazol is a more active PGR compared with non-triazole PGRs. Less active ingredient of paclobutrazol foliar spray was required on an active ingredient per liter basis for effective control of 'Bright Golden Anne' chrysanthemum (Chrysanthemum morifolium Ramat.) stem extension than ancymidol (A-Rest/Reducymol), daminozide, or piperonyl bromide (Alden/Stemtrol). Likewise, less active ingredient of paclobutrazol substrate drench on an active ingredient per pot basis was required for effective control of stem extension than chlorphonium chloride (Phosfon/Phosfleur), but ancymidol drenches required about equal concentrations (Menhenett 1984).

Gerbera daisies planted in 30 cm (12 in) diameter clay pots received apaclobutrazol spray at 0, 25, 50 or 100 ppm (Bekheta et al. 2008). All paclobutrazol concentrations suppressed plant height and increased leaf dry weight. There were also decreases in peduncle lengths (authors reported pedicle) and increases in peduncle diameters, with increasing paclobutrazol concentrations. All paclobutrazol applications increased flower numbers per plant and flower water content.

Similar results have been observed in other plants. Oriental knight's-spur (*Consolida orientalis* Schrödinger) was treated with a paclobutrazol foliar spray at 0, 125, 250 or 500 ppm when 5% of plants had elongated the first internodes (Mansuroglu et al. 2009). All paclobutrazol applications reduced plant height, internode length of main and secondary inflorescences, pedicel length, and number of secondary inflorescences. Paclobutrazol spray at 250 ppm increased flower number on the main inflorescence and 500 ppm increased stem diameter and flower number on secondary inflorescences. However, paclobutrazol had no effect on time from sowing to flower.

Paclobutrazol can be used as a substrate drench or foliar spray. Plants of scented bouvardia (*Bouvardia humboldtii* Hend. & Andr. Hend.) received paclobutrazol foliar sprays or substrate drenches (Wilkinson and Richards 1987). The spray treatments were three applications at 250 ppm, two applications at 500 ppm, or one application at 1000 ppm. Drench concentrations were 0–4 mg a.i. per pot. All paclobutrazol treatments reduced plant height and dry weight and increased flower numbers. Spray treatments at 250 and 500 ppm or a drench treatment at 2 mg a.i. per pot were the most effective, and flower numbers were about 35% greater than in control plants.

Paclobutrazol soil drenches appear more active than foliar sprays in controlling plant growth. McDaniel (1983) treated chrysanthemums in 15 cm (6 in) pots with paclobutrazol foliar spray at 0–5 mg a.i. per plant, or drenches at 0–0.75 mg a.i. per plant under both summer and winter conditions. Results from two seasons were similar. Paclobutrazol applications excessively suppressed growth of chrysanthemum cultivars. Compared to foliar sprays, substrate drenches inhibited height extension to a greater extent. paclobutrazol applications did not reduce flower numbers or delay time to flower.

The effect of PGRs can vary by season. ‘Mondriaan’ pot carnation (*Dianthus caryophyllus* L.) received paclobutrazol drenches at 0.45–1.12 mg a.i. per pot or sprays at 0.16–0.65 mg a.i. per pot in spring. In winter, paclobutrazol was applied as drenches at 0.125–0.45 mg a.i. per pot (Bañón et al. 2002). In general, paclobutrazol controlled plant growth and improved commercial quality. In spring, drench applications were more effective than sprays in reducing plant growth. Spring-grown plants produced more flower buds than winter-grown plants. In winter, a drench of 0.25 mg produced better quality plants than the control. All spray and drench concentrations greater than 0.45 mg darkened leaf color slightly. Days from potting to three flowers open was greater in winter-grown than in spring-grown plants for climatological reasons.

Gibberellin biosynthesis inhibitors have effects on particular transitions during flower development (Pharis and King 1985). ‘Shrimp Pink’ table mountain watsonia (*Watsonia tabularis* Mathews & L.Bolus) plants were drenched with 0, 5, 10 or 20 mg paclobutrazol in 100 ml (3.4 oz) distilled water when the second leaf reached 15 cm (5.9 in) in length (Thompson et al. 2005). Paclobutrazol drenches reduced foliage height by 49% ,63% or 75% of the control with increasing concentrations; however, leaf number was not affected. Paclobutrazol also decreased inflorescence heights by 28%, 62% or 83% of the control. Times to first flower was extended by increasing concentrations by 14 days using 20 mg paclobutrazol drench compared with control plants.

Geranium (*Pelargonium ×hortorum* Bailey) was treated with paclobutrazol drenches at 0, 10 or 20 ppm 25 days after pinching (Singh et al. 2016). Plant height and spread were reduced and number of shoots per plant increased with increasing concentrations. Days to flower bud formation and first flower were delayed by paclobutrazol. Paclobutrazol drenches decreased inflorescence diameter and increased number of inflorescences per plant. Palobutrazol application at 10 ppm maximized pot presentability. The number of inflorescences per plant open at a time increased, but the duration of flowering decreased with increasing concentrations.

Ecker et al. (1992) applied paclobutrazol substrate drenches at 0–2.5 mg a.i. per pot to ‘Midget- Red’ stock (*Matthiola incana* (L.) W.T. Aiton), an early flowering and short cultivar, and ‘Lavender’, a late flowering and medium-height cultivar. Both cultivars were treated 20 days after potting when flower buds were visible on ‘Midget-Red but not ‘Lavender’. Paclobutrazol drenches delayed flowering in ‘Lavender’, but not in ‘Midget-Red’. Inflorescence length of both cultivars was reduced by paclobutrazol treatments.

In some species, the flowering process was advanced by paclobutrazol applications. Paclobutrazol drenches at 0–50 mg a.i. per pot and foliar sprays at 0–1000 ppm were applied to great bougainvillea (*Bougainvillea spectabilis* Willd.) plants
grown in 18 cm (7.1 in) pots under long or short natural photoperiods (Karagüzel 1999). In all treatments, time from application to flower decreased slightly under long photoperiods, but not under short photoperiods. Numbers of flowers per plant and shoot length decreased at even the lowest concentration, while shoot number increased under both photoperiods. Floral initiation was also stimulated by paclobutrazol application on *Episcia cupreata* Hanst. (Stamps and Henny 1986) and *Hydrangea macrophylla* (Thunb.) Ser. (Bailey et al. 1986).

Paclobutrazol was recommended at 2.5–5 ppm as a foliar spray or at 0.25–0.5 ppm as a substrate drench for gerbera daisy, but no further details about application were given (GoldSmith Seed 2016). Application as a drench or spray enhanced plant appearance and uniformity, tolerance to drought and transport stress, and resulted in less breakage during handling (Rogers and Tjia 1990).

Plants also responded differently to different PGR application timing. Gilbertz (1992) applied paclobutrazol sprays at 30–60 ppm to chrysanthemum (*Dendranthema ×grandiflorum* (Ramat.) Kitam.) plants at 0, 2 or 4 weeks after pinching. The earlier applications resulted in shorter plants, but the earlier an application was applied, the longer the plants took to flower. Flower size was minimally affected by the treatments.

Caladium (*Caladium* ×*hortulanum* Birdsey) ‘Aaron’, ‘White Christmas’, and ‘Carolyn Wharton’ received paclobutrazol drench treatments at 2 mg a.i. per pot (Barrett et al. 1995). Treatment did not affect height of caladium ‘Aaron’ or ‘White Christmas’ when applied 1 week after planting, but did result in shorter plants when applied 3 weeks after planting.

Pot plant gerberas are commonly market throughout the spring, summer, and into the fall (Hamrick, 2003). However, sowing seeds in summer for finished plants in winter could make gerbera daisy an alternative holiday crop. The objective of this experiment was to determine the effects of paclobutrazol substrate drenches compared with a daminozide foliar spray standard applied at two application stages on growth, flowering, and marketable quality rating of ‘Bright Red with Light Eye’ gerbera daisy for a fall and spring finish time.

Material and Methods

Seeds of ‘Bright Red with Light Eye’ gerbera daisy (Pan American Seed, West Chicago, IL) were sown on Aug. 11, 2015 for the fall season and Dec. 17, 2015 for the spring season, into 128 square cells [5 cm (2 in) tall, 24 cm^3 (1.5 in^3) volume] plug flats (T.O. Plastics, Clearwater, MN) containing germinating substrate (Jolly Gardener Pro-Line Custom Germinating Mix, Oldcastle Lawn & Garden, Inc., Atlanta, GA). Seeds were covered lightly with a coarse-grade vermiculite. The sown plug flats were placed in an unlit germination chamber (GC12, Phytotronics, Inc., Earth City, MO) with a 24 C (76 F) set point temperature. On Aug. 17, 2015 for the fall and Dec. 24, 2015 for the spring when at least 90% of the hypocotyls had emerged, the plug flats were moved into a greenhouse on raised benches under intermittent mist set to run for 15 s every 45 min from 6:00 AM to 4:30 PM. One day later, the plug flats were removed from the intermittent mist, but remained in the same greenhouse. The greenhouse was covered in two layers of polyethylene and an outside layer of white shade cloth.

The heat was set at 18 C (65 F) and ventilation began at 28 C (82 F). On Aug. 20, 2015 for the fall and Dec. 27, 2015 for the spring, the plug flats were moved into an unshaded, 8 mm (0.3 in) twin-wall polycarbonate covered greenhouse with a heating set point of 18 C (65 F) and ventilation began at 26 C (78 F). The plug flats were placed on raised benches and underlain with black felt fabric over black plastic to retain water and irrigated by hand. Seedlings were watered when the substrate appeared dry, but before they wilted. Seedlings were fertilized once per week with a 20N–4.4P–16.5K at 200 ppm N using liquid fertilization (Plant Marvel Nutriculture 20–10–20 Plus, Plant Marvel Laboratories, Inc., Chicago Heights, IL). Seedlings were transplanted into 12.7 cm (5 in) [9.2 cm (3.6 in) deep, 800 cm^3 (48.4 in^3) volume] round plastic pots (Dillen Brand, Myers Industries Lawn & Garden Group, Middlefield, OH) containing substrate (Fafard 3B Mix, Sun Gro Horticulture, Agawam, MA) on Sept. 14, 2015 for the fall and on Feb. 4, 2016 for the spring. Plants were placed on a bench pot-to-pot. Plants were fertilized on constant liquid fertilization with one clear watering per week using the same fertilizer as used on the plug flats beginning when roots were visible at the bottom of the majority of the pots. Pesticide (Insect, Disease & Mite Control Bayer Advanced, Bayer CropScience, Research Triangle Park, NC) was applied at the manufacturer recommended rate every 1–2 weeks after potting for insect and disease control.

Treatments consisted of two replications of season as two simultaneous experimental runs for the spring and fall. PGR treatments were applied at two application stages in each season. Stage 1 was when the majority of pots had roots at the bottom of the pots which occurred on Oct. 9, 2015 for the fall and Mar. 10, 2016 for the spring. Stage 2 was 2 weeks later on Oct. 23, 2015 for the fall and Mar. 24, 2016 for the spring. Six PGR treatments applied at each stage in each season were paclobutrazol substrate drenches at 0, 1, 2, 3, or 4 ppm (0, 0.09, 0.19, 0.28, or 0.38 mg a.i. per pot) and a daminozide foliar spray at 2500 ppm. Paclobutrazol drenches were applied at 88.7 ml (3 oz) per pot (Syngenta Crop Protection 2015). Daminozide sprays were applied at 0.2 $L \cdot m^{-2}$ (equivalent to 2 $qt \cdot 100\ ft^{-2}$) using a CO_2 sprayer with a flat fan spray nozzle (TeeJet 8003VS, Bellspray, Inc., Opelousas, LA) at 310 kPa (45 psi). Temperature and relative humidity for the fall were 28 C (82 F) and 68.7% RH at stage 1 and 29 C (85 F) and 53.2% RH at stage 2, and for the spring 24 C (76 F) and 91.1% RH at stage 1 and 12 C (53 F) and 25.8% RH at stage 2, respectively. There were nine single-pot replications per treatment combination for the fall and eight single-pot replications for the spring.

Initial data were recorded on each plant at each stage and season to document plant sizes at the time PGRs were applied. For the fall, leaf numbers longer than 3 cm (1.2 in) were counted, and plant height, widest width and perpendicular width were measured to calculate size index (SI = (height + widest width + perpendicular width) /3). Foliage height was from the substrate surface to the top of the foliage. For the spring, only leaf counts and SI were determined. Pots were spaced 23 cm (9 in) on center on Oct. 24, 2015 for the fall and March 22, 2016 for the spring.

The dates of the first fully-opened flower (inflorescence) were recorded for fall and spring; first flower was when ray flowers on the first inflorescence were fully reflexed perpendicular to the peduncle. At first flower, flower and flower bud counts, foliage SI, flower diameter, and peduncle length were determined. Peduncle length was measured from the peduncle point of origin on the crown to the base of the calyx. A quality rating was assigned when 2or 3 flowers were open on each pot. The quality ratings were: 1) lower foliage extending 20-30% beyond the pot rim, with tightly spaced, distorted leaves; flowers opened just above foliage on very short peduncles; 2) lower foliage extending 30-50% beyond the pot rim. Leaves less tightly spaced and less distorted than in 1; flowers opened on peduncles that appeared twice as long as in 1; 3) lower foliage extending 60-70% beyond the pot rim; leaf spacing appeared less tightly spaced than 2, but not as open as 4 with no foliar distortion. Flowers opened on peduncles that appeared four times as long as in 1; 4) plants appeared open and spindly. Lower foliage extending 70-80% beyond the pot rim; leaf spacing open with substrate visible; no leaf distortion; flowers opened on peduncles that appeared six times as long as in 1.

To assess consumer preference, a survey was conducted in the Department of Horticulture at Auburn University on Nov. 19–20, 2015 for the fall and on Apr. 18–19, 2016 for the spring. Four plants were selected for the survey fitting the quality rating criteria with 2 or 3 open flowers. Faculty, staff, and undergraduate and graduate students were contacted by e-mail and invited to "select the plant you would be willing to purchase from a garden center" on a survey form. Participants also indicated whether they were faculty, staff, undergraduate or graduate students.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was a split-split-plot with seasons in the main plot, application stages in the sub-plot, and PGR treatments in the sub-sub-plot for all responses except initial plant sizes and the survey results. Initial plant size responses were analyzed as a split plot with seasons in the main plot, application stages in the sub-plot. Initial SI was used as a covariant in the model for data recorded at first flower where it improved model fit based on Akaike information criterion (AIC) statistics. Where residual plots and a significant covariance test for homogeneity indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Least squares means comparisons between seasons and application stages were tested using F-tests. Least squares means comparisons of the daminozide standard to the paclobutrazol concentrations were tested using Dunnett's method. Linear and quadratic trends over paclobutrazol concentrations were tested using orthogonal polynomials. Quality ratings were analyzed using the multinomial probability distribution and differences in seasons were estimated using the simulated method. Counts within each quality rating level for the survey were analyzed using the negative binomial probability distribution and differences among levels were determined using the simulated method. All significances were at $\alpha = 0.05$ unless otherwise indicated.

Results

Application stage was significant for initial leaf counts, foliage height, and SI (Table 1). Plants had more leaves, higher foliage height, and greater SI at stage 2 than stage 1.

The season by PGR, application stage by PGR, and season by stage interactions were significant for foliage height. Foliage height decreased linearly by 27.9% for fall, but only 13.6% for spring with increasing paclobutrazol concentrations (Table 2). Foliage height for fall was 72%–107% higher than for spring across all paclobutrazol concentrations. Foliage height of plants for fall were higher when treated with 0 or 1 ppm paclobutrazol than that of plants treated with daminozide, but lower when treated with 4 ppm paclobutrazol. There were no differences between the paclobutrazol and daminozide treatments for spring.

Foliage height decreased linearly by 20.7% in stage 1 and 25.5% in stage 2 with increasing paclobutrazol concentrations. Foliage height in stage 2 was 12.3%–21.5% higher than in stage 1 across all paclobutrazol concentrations. Foliage heights of plants in stage 2 were higher when treated with 0 and 2 ppm paclobutrazol than plants in stage 1. In stage 1, foliage height of plants treated with 4 ppm paclobutrazol were lower than that of plants treated with daminozide while in stage 2, plants treated with 0 ppm paclobutrazol had higher foliage heights than plants treated with daminozide.

For fall, stage 2 plants were 10.8% taller than in stage 1, but similar for spring. Foliage height of plants was higher for fall than for spring by 76.2% in stage 1 and by 101.6% in stage 2.

The season by PGR interaction was significant for SI and quality rating. SI and quality rating decreased linearly with increasing paclobutrazol concentrations in both seasons. SI decreased linearly by 16.3% for fall, but only by 4.7% for spring. SI was larger for fall than spring across all paclobutrazol concentrations by 18.5%–35.3%. For fall, SI of plants treated with 0 ppm paclobutrazol was larger than that of daminozide treated plants, but smaller than that of plants treated with daminozide when treated with 4 ppm paclobutrazol. In the spring, SI of plants treated at 3 and 4 ppm paclobutrazol were 9.8% and 8.9%, respectively, smaller than in daminozide treated plants. Plants treated with 0 or 1 ppm paclobutrazol had higher quality ratings for fall than for spring. Plants had higher quality ratings for fall when treated with 0 or 1 ppm paclobutrazol than plants treated with daminozide. For spring, plants treated with 0 ppm paclobutrazol had higher quality rating than daminozide treated plants.

In the consumer preference survey, there were no differences between the two years or among departmental positions (data not shown). Among the four quality levels, plants assigned level 3 had a higher count than the other three levels comprising 63.3% of total participants. There were no differences in the remaining levels.

The season and PGR main effects were significant for days to first flower (DTF) and peduncle length (Table 3). With increasing paclobutrazol concentration, DTF changed quadratically by 2 days. Spring-grown plants flowered 1 day later than fall-grown plants. There were no differences in DTF between plants treated with paclobutrazol and daminozide.

Increasing paclobutrazol concentrations decreased peduncle lengths linearly by 14.4%. Peduncles were 27.4% longer for fall than for spring. Plants treated with a 0 or 1 ppm paclobutrazol drench had longer peduncles than those treated with daminozide.

Only the PGR main effect was significant for flower diameter. Increasing paclobutrazol concentrations decreased flower diameter linearly by 4.3%. There were no differences between paclobutrazol and daminozide treated plants. Spring-grown plants had one more flower and bud than fall-grown plants.

Discussion

In this study, paclobutrazol treatments were effective in reducing foliage height and SI of gerbera daisy. The same effect of paclobutrazol on plant height of gerbera daisy was previously reported (Bekheta et al. 2008), and other ornamental plants, like 'Bright Golden Anne' chrysanthemum (Menhenett, 1984), 'Mondriaan 'pot carnation (Bañón et al. 2002), and oriental knight's-spur (Mansuroglu et al. 2009).

Peduncle length decreased with increasing paclobutrazol concentrations. These results agree with reports that PGRs decreased peduncle length in gerbera daisy (Armitage 1984; Bekheta et al. 2008), panicle length in butterfly-bush (B*uddleia davidii* Franch.) 'Dubonnet' (Ruter 1992), pedicel length in oriental knight's-spur (Mansuroglu et al. 2009) and inflorescence length of stock 'Midget- Red' and 'Lavender' (Ecker et al. 1992).

First open flower was delayed 2 days by the highest concentration of paclobutrazol, but this small difference may not have horticultural significance. This delay agreed with results for 'Mondriaan 'pot carnation (Bañón et al. 2002), stock 'Lavender' (Ecker et al. 1992), and geranium (Singh et al. 2016). However, paclobutrazol application did not delay flowering of chrysanthemum (McDaniel 1983) or oriental knight's-spur (Mansuroglu et al. 2009).

Flower numbers were not affected by paclobutrazol applications on gerbera daisy, in agreement with McDaniel (1983) on chrysanthemum. However, in 'Mondriaan' pot carnation (Bañón et al. 2002) and butterfly-bush 'Dubonnet' (Ruter 1992), flower numbers decreased with increasing paclobutrazol concentrations while in gerbera daisy (Bekheta et al. 2008), oriental knight's-spur (Mansuroglu et al. 2009) , geranium (Singh et al. 2016) and scented bouvardia (Wilkinson and Richards 1987), paclobutrazol increased flower numbers. Wilkinson and Richards (1987) proposed that the increase in flower numbers in scented bouvardia may have resulted from paclobutrazol diverting assimilates into flower development because of reduced demand by roots or, paclobutrazol may have reduced gibberellin biosynthesis in plants that promoted flower formation.

Application of the appropriate concentration of paclobutrazol drench improved gerbera daisy market quality. This same result was found with 'Mondriaan' pot carnation (Bañón et al. 2002); paclobutrazol controlled plant growth and improved commercial quality.

Season resulted in differences in plant size. This may have resulted from the warmer and brighter conditions during seedling development in fall than in spring. However, in 'Mondriaan' pot carnation, there was no difference in plant size between spring-grown and winter-grown plants (Bañón et al. 2002). Also, in chrysanthemum (McDaniel 1983), plants treated under both summer and winter conditions were similar. Fall season and spring season flower and bud number only differed from each other by one flower, even though these two seasons had different light conditions. This result disagreed with result in cut gerbera daisy (Lin and French, 1985) that plants produced more flowers under short photoperiod.

Application stage only affected foliage height. This disagreed with findings in gerbera daisy (Armitage 1984), caladium (Barrett et al. 1995) and chrysanthemum *(*Gilbertz 1992), where application stage made differences in plant response.

In the survey, plants rated level 3 were most often chosen as the "plant they would likely purchase from a garden center" by consumers. In fall, plants treated with palobutrazol drenches at 1 and 2 ppm received a rating of 3, but in spring, plants treated with paclobutrazol at 0, 1, 2, and 3 ppm received a rating of 3. Based on quality ratings, the 2500 ppm daminozide was likely too high for high consumer preference as were the highest concentrations of paclobutrazol.

Increasing rates of paclobutrazol drench treatment effectively controlled plant growth by decreasing foliage height, plant size index, and peduncle length. PGR applications also delayed flowering, and decreased flower diameter and flower and bud counts, but these differences were small and not considered of practical importance. Plant were larger in the fall than the spring, but there were only small differences in foliage height between stages. We suggest 1 or 2 ppm paclobutrazol substrate drench in 12.7 cm (5 in) pots to improve the commercial quality of gerbera daisy for a fall finish. Hamrick (2003) recommended 1000–2500 ppm daminozide at 12–14 days after transplanting. Therefore, a lower concentration within this range might provide a higher consumer preference for this cultivar. Gerbera daisies were of excellent quality with a fall finishing and has potential in the floral market for the holiday season. Additional research is needed to identity optimal application time for drench application of paclobutrazol to ensure use quantity minimum concentration to get the best control of plant growth from an economic standpoint.

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Table 3.1. Plant sizes of *Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye' (Mega series) at the time of plant growth retardant treatments at two stages of development.[z]

Stage[y]					
1	2	1	2	1	2
Leaf count[x]		Foliage height (cm)[w]		Size index (cm)[v]	
7b[u]	10a	6.5b	9.4a	12.2b	16.9a

[z]The stage of development main effect was significant at $P < 0.05$.
[y]Stage 1 was when the majority of plants had roots visible at the bottom of the substrate. Stage 2 was 2 weeks after stage 1.
[x]Leaves longer than 3 cm (1.2 in).
[w]Foliage height was from the substrate surface to the top of the foliage.
[v]Size index = (foliage height + widest width + width perpendicular to first width) / 3.
[u]Least squares means comparison using main effect F-test at $P < 0.05$.

Table 3.2. Effects of growing season, plant stage of development, and drench applications of paclobutrazol as compared to a daminozide standard foliar spray on foliar height, size index, and market quality rating of *Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye'.

	Paclobutrazol (ppm)					Daminozide	
	0	1	2	3	4	2,500 ppm	Significance[z]
Season[y]				Foliage height (cm)[x]			
Fall 2015	13.6a*[w]	13.6a*	11.8a	10.1a	9.8a*	11.5a	L***
Spring 2016	6.6b	6.6b	5.7b	5.8b	5.7b	6.8b	L*
Stage[v]							
1	9.2b	10.1ns	7.9b	8.0ns	7.3ns*	9.6ns	L***
2	11.0a*	10.1	9.6a	7.9	8.2	8.8	L***

	Stage	
Season	1	2
Fall 2015	11.1aB[u]	12.3aA
Spring 2016	6.3bNS	6.1b

Season				Size index (cm)[t]			
Fall 2015	27.6a*	27.0a	25.7a	24.1a	23.1a*	25.7a	L***
Spring 2016	20.4b	21.3b	19.8b	19.3b*	19.5b*	21.4b	L*

Season				Quality rating[s]			
Fall 2015	4a*[r]	3a*	3ns	2ns	2ns	2ns	L***
Spring 2016	3b*	3b	3	3	2	2	L***

Survey quality rating counts[q]			
1	2	3	4
12b[p]	16b	62a	8b

[z]Significant linear (L) trends over paclobutrazol concentrations using orthogonal polynomials at $P < 0.05$ (*) or 0.001 (***).
[y]Fall seed sowing was on Aug. 11, 2015 and spring seed sowing was on Dec. 17, 2015.

[x]The season by plant growth retardant (PGR) treatment, stage by PGR, and season by stage interactions were significant at $P < 0.05$. Foliage height was from the substrate surface to the top of the foliage.
[w]Least squares means comparisons between seasons and stages (lower case in columns) using F-tests (ns = not significant), and comparisons of paclobutrazol concentrations to the daminozide standard using Dunnett's method at $P < 0.05$ (*).
[v]Stage 1 was when the majority of plants had roots visible at the bottom of the substrate. Stage 2 was 2 weeks after stage 1.
[u]Least squares means comparisons between seasons (lower case in columns) and stages (upper case in rows) using the F-tests at $P < 0.05$.
[t]Size index = (foliage height + widest width + width perpendicular to first width) / 3. The season by PGR interaction was significant at $P < 0.05$.
[s]The season by PGR interaction was significant at $P < 0.05$. Reported are medians.
[r]Quality rating categories: 1) Lower foliage extending 20-30% beyond the pot rim, with tightly spaced, distorted leaves. Flowers opened just above foliage on very short peduncles; 2) Lower foliage extending 30-50% beyond the pot rim. Leaves less tightly spaced and less distorted than in 1. Flowers opened on peduncles that appeared twice as long as in 1; 3) Lower foliage extending 60-70% beyond the pot rim. Leaf spacing appeared ideal with no foliar distortion. Flowers opened on peduncles that appeared four times as long as in 1; 4) Plants appeared open and spindly. Lower foliage extending 70-80% beyond the pot rim. Leaf spacing open with substrate visible. No leaf distortion. Flowers opened on peduncles that appeared six times as long as in 1. Comparisons of the daminozide standard to the paclobutrazol concentrations and between seasons were estimated using the Shaffer-simulated method at $P < 0.05$.
[q]Consumer quality survey conducted in fall 2015 and spring 2016 in the Department of Horticulture at Auburn University. Faculty, staff, graduate students, and undergraduate students were contacted by mass e-mail and asked to complete a survey form. Participants were presented with one representative plant from each quality rating category with two flowers open and asked to indicate their choice of a plant they would likely purchase.
[p]Comparisons among rating counts (upper case in row) using the simulated method at $P < 0.05$.

Table 3.3. Effects of growing season, plant stage of development, and drench applications of paclobutrazol as compared to a daminozide standard on days to first open flower from transplant (DTF), flower peduncle length, flower and bud count, and flower diameter of *Gerbera jamesonii* 'Bright Red with Light Eye' (Mega series).

Paclobutrazol (ppm)					Daminozide	
0	1	2	3	4	2500 ppm	Significance^{z}
			DTF^{y}			
62	62	62	62	64	63^{x}	Q*
		Season^{w}				
Fall 2015	62b^{v}	Spring 2016	63a			
			Peduncle length (cm)^{u}			
15.3*	15.2*	14.0	13.6	13.1	13.4	L***
		Season				
Fall 2015	15.8a	Spring 2016	12.4b			
			Flower diameter (cm)^{t}			
9.3	9.4	9.4	8.9	8.9	9.1	L**
		Flower and bud count^{s}				
		Season				
Fall 2015	3b	Spring 2016	4a			

^{z}Significant linear (L) or quadratic (Q) trends over paclobutrazol concentrations using orthogonal polynomials at $P < 0.05$ (*), 0.01 (**), or 0.001 (***).
^{y}The season and plant growth retardant treatment main effects were significant at $P < 0.05$. A flower was open when the ray floret petals were reflexed perpendicular to the peduncle.
^{x}Least squares means comparisons of paclobutrazol concentrations to the daminozide standard using Dunnett's method at $P < 0.05$ (*).
^{w}Fall seed sowing was on 11 Aug. 2015 and spring seed sowing was on 17 Dec. 2015.
^{v}Least squares means comparison in seasons using main effect F-test at $P < 0.05$.
^{u}Peduncle length was measured from the peduncle point of origin to the base of the calyx.
^{t}The PGR main effect was significant at $P < 0.05$.
^{s}The season main effect was significant at $P < 0.05$.

Figure 3.1. One representative plants with 2–3 open flowers from each rating category[z]

[z]Quality rating categories: 1) Lower foliage extending 20–30% beyond the pot rim, with tightly spaced, distorted leaves. Flowers opened just above foliage on very short peduncles; 2) Lower foliage extending 30–50% beyond the pot rim. Leaves less tightly spaced and less distorted than in 1. Flowers opened on peduncles that appeared twice as long as in 1; 3) Lower foliage extending 60–70% beyond the pot rim. Leaf spacing appeared ideal with no foliar distortion. Flowers opened on peduncles that appeared four times as long as in 1; 4) Plants appeared open and spindly. Lower foliage extending 70–80% beyond the pot rim. Leaf spacing open with substrate visible. No leaf distortion. Flowers opened on peduncles that appeared six times as long as in 1. Comparisons of the daminozide standard to the paclobutrazol concentrations and between seasons were estimated using the Shaffer-simulated method at $P < 0.05$.

CHAPTER IV

Effects of Application Timing, and Substrate Drench Applications of Paclobutrazol as Compared to Daminozide Standards on Growth and Flowering of Gerbera Daisy 'Bright Red with Light Eye'[4]

Y. Chen[5], J.R. Kessler, Jr.[3], G.J. Keever, and G.B. Fain

Abstract

The objective of this work was to determine the optimal application timing and concentration for applying a paclobutrazol (Bonzi) substrate drench as compared to daminozide (B-Nine) foliar spray standards for plant size control and improved market quality of gerbera daisy (*Gerbera jamesonii* Hook. f.) 'Bright Red with Light Eye'. Plants in 12.7 cm (5 in) pots were treated with a substrate drench of 0, 1.5, or 3 ppm paclobutrazol or a 2500 ppm daminozide foliar spray at weekly intervals from 2–6 weeks after transplanting (WAT). A 2500 ppm daminozide standard was applied 2 WAT and again 10 days later. Foliage height, plant size index, flower diameter, peduncle length, and quality rating decreased, while days to first open flower (DTF) increased linearly or quadratically with increasing paclobutrazol concentration regardless of application timing. Increasing WAT resulted in earlier flowering and a reduction in peduncle length, regardless of plant growth retardant (PGR) treatment. Foliage height, size index, flower diameter, peduncle length, and quality rating of plants receiving daminozide weekly were less than or not different from 0 ppm paclobutrazol, but greater than those receiving 1.5 or 3 ppm

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paclobutrazol. Foliage height, size index, and peduncle length of plants receiving daminozide at 2 WAT were greater than those receiving 1.5 or 3 ppm paclobutrazol, but not different from those receiving 0 or 1.5 ppm. Flower diameter and DTF of plants receiving daminozide at 2 WAT were not different from plants receiving paclobutrazol drench treatments. Quality rating was higher for plants receiving daminozide at 2 WAT than those receiving 1.5 or 3 ppm paclobutrazol. There were no differences in plants that received daminozide at 2 weeks and those that received daminozide twice. Treatments did not affect time to flower senescence. Based on quality ratings, no growth retardant, regardless of concentration or timing produced the highest quality rating. The ineffectiveness of PGR treatments may have been because the study was conducted in the summer when temperatures and light intensities were higher than at other times of the year.

Index words: plant growth retardant, B-Nine, Bonzi, application stage, greenhouse production.

Chemicals used in this study; B-Nine (daminozide) [butanedioic acid mono (2,2-dimethylhydrazide)] and Bonzi (paclobutrazol) [(±)-(R*,R*)-β-[(4-Chlorophenyl)methyl]-α-(1,1-dimethylethyl)-lH-1,2,4-triazole-1-ethanol].

Species used in this study: Gerbera daisy (*Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye').

Significance to the Horticulture Industry

Generally, paclobutrazol is an effective and long-lasting plant growth retardant for many greenhouse crops, and may be more effectively applied as a substrate drench than a foliar spray. In addition, plants also response differently to different application time of paclobutrazol. In this study, gerbera daisy in 12.7 cm (5 in) pots were treated with 0, 1.5, or 3 ppm paclobutrazol substrate drenches or a 2500 ppm daminozide foliar spray weekly at 2–6 WAT. A daminozide standard was applied at 2500 ppm 2 WAT and again 10 days later. Paclobutrazol drenches decreased foliage height, plant size index, flower diameter, and peduncle length, regardless of application time. However, paclobutrazol drenches also decreased quality rating. The highest concentration of paclobutrazol delayed flowering by 2 days, but this was not considered of practical importance. Peduncle length and DTF decreased with increasing WAT, regardless of PGR treatment. There were no differences in daminozide applied at 2 weeks and daminozide applied twice. Treatments did not affect flower longevity. Based on quality ratings, no growth retardant, regardless of concentration or timing produced the highest quality rating. The ineffectiveness of PGR treatments may have been because the study was conducted in the summer when temperatures and light intensities were higher than at other times of the year.

Introduction

Paclobutrazol is an effective plant growth retardant (PGR) for controlling plant size in many species, like gerbera daisy (Bekheta et al. 2008), oriented knight's-spur (*Consolida orientalis* Schrödinger) (Mansuroglu et al. 2009), scented bouvardia (*Bouvardia humboldtii* Hend. & Andr. Hend.) (Wilkinson and Richards 1987) and chrysanthemums (*Chrysanthemun ×morifolium* Ramat.) (McDaniel 1983). It inhibited stem elongation in sunflower (*Helianthus annuus* L.) (Wample and Culver 1983) and soybean (*Glycine max* (L.) Merr.) (Sankhla et al. 1985), darkened leaves in oriented knight's-spur (Mansuroglu et al. 2009), reduced peduncle length in gerbera daisy (Armitage 1984, Bekheta et al. 2008), panicle length in 'Dubonnet' butterfly-bush (B*uddleia davidii* Franch.) (Ruter 1992), and pedicel length in oriental knight's-spur (Mansuroglu et al. 2009). Paclobutrazol delayed flowering (Bañón et al. 2002, Singh et al. 2016, Thompson et al. 2005) or enhanced flowering (Bailey et al. 1986, Karagüzel 1999, Stamps and Henny 1986), increased flower number (Bekheta et al. 2008, Mansuroglu et al. 2009, Singh et al. 2016, Wilkinson and Richards 1987) or decreased flower number (Bañón et al. 2002, Ruter 1992). Also, paclobutrazol has exhibited senescence-delaying properties. The percentage of senesced flowers in stock (*Matthiola incana* (L.) W.T. Aiton) 'Midget- Red' recorded 30 days after the onset of flowering decreased from 67% to 0% with increasing paclobutrazol rates. Similar results were observed in stock 'Lavender' (Ecker et al.1992).

Plants responded differently to different PGR application timings. Armitage et al. (1984) applied ancymidol at 200 ppm and daminozide at 4000 ppm to gerbera daisy as foliar sprays 5–8 weeks after transplanting (WAT). Treatments were repeated 10 days later. Plants had reduced peduncle length, total height, and vegetative height when ancymidol was applied at 6–7 WAT compared with other treatments. Daminozide treated plants had visible buds earlier than those treated with ancymidol. Plants treated with daminozide 6 WAT reached visible buds earlier than the control. Daminozide more effectively controlled peduncle length, total height, and vegetative growth when applied 8 WAT. Leaf number and flower diameter were not affected by PGR treatments.

Gilbertz (1992) applied paclobutrazol sprays at 30–60 ppm to chrysanthemum (*Dendranthema ×grandiflorum* (Ramat.) Kitam.) at 0, 2 or 4 weeks after pinching. Earlier applications resulted in shorter plants, but delayed flowering. Flower size was minimally affected by treatments.

Caladium (*Caladium ×hortulanum* Birdsey) 'Aaron', 'White Christmas', and 'Carolyn Wharton' received paclobutrazol drench treatments (Barrett et al. 1995). Drenches at 2.0 mg a.i. per pot did not affect height of caladium 'Aaron' or 'White Christmas' when applied 1 week after planting, but did result in shorter plants when applied 3 weeks after planting. The author proposed that the amount of roots present to take up paclobutrazol drenches may have led to differences in timing of application.

Daminozide was recommended for gerbera daisy as a foliar spray at 1000–2500 ppm, once or twice 9–10 days apart with the first application made 12–14 days after transplanting if required (Hamrick 2003, PanAmerican Seed 2015). Paclobutrazol was recommended at 2.5–5.0 ppm as a foliar spray or at 0.25–0.5 ppm (0.078–0.625 mg a.i per 15.2 cm (6 in) or larger pot) as a substrate drench (GoldSmith Seed 2016). However, no more detail about application time was given. The objective of this work was to examine the effects of application timing and substrate drench applications of paclobutrazol as compared to daminozide standards on growth and flowering of gerbera daisy.

Material and Methods

This study was conducted in two experimental runs. Seeds of 'Bright Red with Light Eye' gerbera daisy (Pan American Seed, West Chicago, IL) were sown on Feb. 3, 2016 in the first run and Mar. 28, 2016 in the second run, into 128 square cell, [5 cm (2 in) tall, 24 cm^3 (1.5 in^3) volume] plug flats (T.O. Plastics, Clearwater, MN) containing germinating substrate (Jolly Gardener Pro-Line Custom Germinating Mix, Oldcastle Lawn & Garden, Inc., Atlanta, GA). Seeds were lightly covered with coarse-grade vermiculite. The sown plug flats were placed in an unlit germination chamber (GC12, Phytotronics, Inc., Earth City, MO) with a 24 C (76 F) set point temperature.

On Feb. 9, 2016 in the first run and Apr. 3, 2016 in the second run, when at least 90% of the hypocotyls had emerged, the plug flats were moved into a greenhouse on raised benches under intermittent mist set to run for 15 s every 45 min from 6:00 AM to 4:30 PM. One day later, the plug flats were removed from intermittent mist, but remained in the same greenhouse. The greenhouse was covered in two layers of polyethylene with an outside layer of white shade cloth. The heat set point was set at 18 C (65 F) and ventilation was in four stages in 1 C (2 F) increments beginning at 24 C (76 F). Evaporative cooling started at 28 C (82 F). On Feb. 13, 2016 in the first run and Apr. 6, 2016 in the second run, flats were placed in an un-shaded, 8 mm (0.3 in) twin-wall polycarbonate covered greenhouse on elevated benches with a heat set point of 18 C (65 F) and ventilation was in four stages at 1 C (2 F) increments beginning at 22 C (72 F). Evaporative cooling started at 26 C (78 F). The plug flats were placed on raised benches and underlain with black felt fabric over black plastic to retain water and irrigated by hand. Seedlings were watered when the substrate appeared dry, but before they wilted. Seedlings were fertilized with a 20N–4.4P–16.5K fertilizer at 200 ppm N using liquid fertilization (Plant Marvel Nutriculture 20-10-20 Plus, Plant Marvel Laboratories, Inc., Chicago Heights, IL) weekly. Seedlings were transplanted into 13 cm (5 in) [9.2 cm (3.6 in) tall, 800 cm^3 (48.4 in^3) volume] round plastic pots (Dillen Brand, Myers Industries Lawn & Garden Group, Middlefield, OH) containing substrate (Fafard 3B Mix, Sun Gro Horticulture, Agawam, MA) on Mar. 23, 2016 in the first run and May 9, 2016 in the second run. Plants were placed pot-to-pot on a greenhouse bench. Plants were fertilized on constant liquid fertilization with one clear water per week using the same fertilizer as used on the plug flats beginning when roots were visible at the bottom of the majority of the pots. Pesticide (Insect, Disease & Mite Control Bayer Advanced, Bayer CropScience, Research Triangle Park, NC) was applied at the manufacturer recommended concentration every 1–2 weeks after potting for insect and disease control.

Plant growth retardant treatments were applied weekly at 2–6 WAT in the first run and at 2–5 WAT in the second run. Applications were made on Apr. 6, Apr. 13, Apr. 20, Apr. 27, and May 4, 2016 in the first run and May 23, May 30, June 2, June 6, and June 13, 2016 in the second run. A paclobutrazol (Bonzi, Syngenta Crop Protection, LLC, Greensboro, NC) substrate drench at 0, 1.5, or 3 ppm (0, 0.14 or 0.28 mg a.i. per pot) and a daminozide (B-Nine WSG, OHP, Inc., Mainland, PA) foliar spray at 2500 ppm were applied at each date. In addition, daminozide foliar sprays were applied at 2500 ppm 2 WAT and again 10 days later on Apr. 16, 2016 in the first run and June 2, 2016 in the second run. Paclobutrazol substrate drenches were applied at 88.7 ml (3 oz.) per pot (Syngenta Crop Protection 2015). Daminozide sprays were applied at 0.2 $L \cdot m^{-2}$ (equivalent to 2 $qt \cdot 100\ ft^{-2}$) using a CO_2 sprayer with a flat fan spray nozzle (TeeJet 8003VS, Bellspray, Inc., Opelousas, LA) at 310 kPa (45 psi). Temperature and relative humidity at 2, 3, 4, 5, and 6 WAT, and 24 days after transplanting were 22 C (71 F) and 90.1% RH, 18 C (65 F) and 84.7% RH, 28 C (82 F) and 68.9% RH, 28 C (83 F) and 88.5% RH, 24 C (76 F) and 78.6% RH, and 21 C (70 F) and 81.4% RH, respectively in the first run. In the second run, temperature and relative humidity at 2, 3, 5, 6 WAT, and 24 days after transplanting were 26 C (78 F) and 91.3% RH, 25 C (77 F) 78.6% RH, , 26 C (79 F) and 83.1% RH, 27 C (80 F) 75.5% RH, and 26 C (78F) and 71.0% RH, respectively. There were nine single-pot experimental units per treatment in the first run and seven experimental units in the second run.

Initial data were recorded on each plant at each treatment date in each experiment. In both experiment runs, leaves longer than 3 cm (1.2 in) were counted, and foliage height, widest width and width perpendicular to the first width were measured to calculate size index [SI = (height + widest width + width perpendicular to the first width) /3]. Pots were spaced 23 cm (9 in) on center on Apr. 7, 2016 in the first run and May 24, 2016 in the second run.

The dates of the first fully-opened flower (inflorescence) were recorded for both experimental runs; first flower was when ray flowers on the first inflorescence were fully reflexed perpendicular to the peduncle. At first flower, flower and flower bud count, foliage size index, flower diameter, and peduncle length were recorded. Foliage height was from the substrate surface to the top of the foliage. Peduncle length was from the peduncle point of origin on the crown to the base of the calyx. A quality rating was assigned when 2 or 3 flowers were open on each pot. The quality rating scale was 1) lower foliage extending 20–30% beyond the pot rim, with tightly spaced, distorted leaves; flowers opened just above foliage on very short peduncles; 2) lower foliage extending 30–50% beyond the pot rim. Leaves less tightly spaced and less distorted than in 1; flowers opened on peduncles that appeared twice as long as in 1; 3) lower foliage extending 60–70% beyond the pot rim; leaves appeared ideal, less tightly spaced than 2, but not as open as 4 with no foliar distortion; flowers opened on peduncles that appeared four times as long as in 1; 4) plants appeared open and spindly. Lower foliage extending 70–80% beyond the pot rim; leaf spacing open with potting media visible; no leaf distortion; flowers opened on peduncles that appeared six times as long as in 1. Flower senescence date was recorded when ray floret petals started curling and wilting.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). Initial plant size responses were analyzed as completely randomized designs. The experimental design for data recorded at first flower was a split-plot with WAT in the main plot and PGR treatments in the sub-plot. The two experimental runs were included in the models as a random variable. Initial leaf counts or foliage heights were used as a covariant in the models (ANCOVA) when it improved model fit based on Akaike information criterion (AIC) statistics. When residual plots and a significant covariance test for homogeneity indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Estimated least squares means paired differences were tested using the simulated method. Quality ratings were analyzed using the multinomial probability distribution with a cumulative log link. Linear and quadratic trends over paclobutrazol concentrations and WAT were tested using orthogonal polynomials. All significances were at $\alpha = 0.05$.

Results

At the time of PGR applications, leaf count increased linearly by 8, and foliage height and size index increased quadratically by 389% and 264%, respectively, with increasing WAT (Table 1).

Foliage height, plant size index, flower diameter, and peduncle length decreased linearly or quadratically by 27.1%, 17.7%, 6.1%, and 19.6%, respectively, while days to first open flower (DTF) increased quadratically by 2 days with increasing paclobutrazol concentration, regardless of application timing (Tables 2 and 3). Only the PGR main effect was significant for foliage height, size index, and flower diameter. Foliage height and size index of plants receiving daminozide weekly were 10.7% and 6.7% less than those receiving 0 ppm paclobutrazol, but 14.7% and 8.5% greater than those receiving 1.5 ppm paclobutrazol, and 22.5% and 13.4% larger than those receiving 3 ppm paclobutrazol (Table 2). Foliage height and size index of plants receiving daminozide at 2 weeks were 18.3% and 14.7% larger than those receiving 1.5 ppm paclobutrazol, and 26.5% and 19.8% larger than those receiving 3 ppm paclobutrazol, but they were not different from those receiving 0 ppm.

Flower diameter of plants receiving daminozide weekly were 5.4% larger than those receiving 1.5 or 3 ppm paclobutrazol, but not different from those receiving 0 ppm. Flower diameter of plants receiving daminozide at 2 weeks was not different from plants receiving paclobutrazol drenches. Foliage height, size index, and flower diameter were not different for plants treated with daminozide at 2 weeks and plants treated with daminozide twice.

The PGR and WAT main effects were significant for peduncle length and DTF. Peduncle length of plants receiving daminozide weekly were 13.1% and 21.5% greater than those receiving 1.5 and 3 ppm paclobutrazol, respectively, but not different from those receiving 0 ppm (Tables 3). Peduncle length of plants receiving daminozide at 2 weeks were 23.7% greater than those receiving 3 ppm paclobutrazol, but not different from those receiving 0 or 1.5 ppm. Peduncle length decreased linearly by 27.1% with increasing WAT, regardless of PGR treatment.

Days to first flower were 3 days longer for plants receiving 3 ppm paclobutrazol than daminozide weekly, but not different from 0 or 1.5 ppm. DTF of plants receiving daminozide at 2 weeks were not different from those receiving paclobutrazol. Days to flower decreased linearly by 6 days with increasing WAT, regardless of PGR treatment. There were no differences in daminozide applied at 2 weeks and daminozide applied twice for peduncle length and DTF.

Quality rating decreased with increasing paclobutrazol concentration, and was higher for plants receiving daminozide weekly and at 2 WAT than those receiving 1.5 or 3 ppm paclobutrazol, but was not different from that of controls. There was no difference in quality ratings between daminozide applied at 2 weeks and daminozide applied twice. Quality rating also decreased linearly with increasing WAT regardless of PGR treatment (Table 4). Treatments did not affect flower longevity.

Discussion

In this study, paclobutrazol drenches reduced foliage height and size index of gerbera daisy. The same effect of paclobutrazol applications on gerbera daisy was reported (Bekheta et al. 2008), and on pot chrysanthemum ‘Bright Golden Anne’ (Menhenett 1984) , ‘Mondriaan’ pot carnation (Bañón et al. 2002), and oriental knight’s-spur (Mansuroglu et al. 2009). Flower diameter was reduced with increasing paclobutrazol concentrations, while daminozide spray did not affect flower diameter. This agrees with former results on gerbera daisy that flower diameter was not affected by daminozide spray (Armitage 1984).

Peduncle length decreased with increasing paclobutrazol drench concentrations. This agrees with reports that paclobutrazol sprays decreased peduncle length in gerbera daisy (Bekheta et al. 2008) and pedicel length in oriental knight's-spur (Mansuroglu et al. 2009) while paclobutrazol drench decreased panicle length in butterfly-bush ‘Dubonnet’ (Ruter 1992), and inflorescence length of ‘Midget- Red’ and ‘Lavender’ stock (Ecker et al. 1992).

Peduncle length also decreased with increasing WAT which agrees with results that later daminozide applications resulted in shorter peduncle length on gerbera daisy (Armitage 1984) and later paclobutrazol drenches were more effective at controlling plant size of caladium compared with earlier drenches (Barrett et al. 1995). However, a study on chrysanthemum found that earlier spray applications resulted in shorter plants than later spray applications (Gilbertz 1992). The author proposed that the earlier treatments probably permitted more chemical contact with the soil and more complete stem coverage because plants had fewer leaves than plants in later treatments. Therefore, the greater surface area of larger plants allowed less chemical contact with active uptake sites.

Days to first flower was delayed 2 days by the highest concentration of paclobutrazol when compared to 0 ppm, but this difference may not have horticultural importance. This delay agreed with results for ‘Mondriaan ‘pot carnation (Bañón et al. 2002), stock ‘Lavender’ (Ecker et al. 1992), and geranium (Singh et al. 2016). However, paclobutrazol application did not delay flowering of chrysanthemum (McDaniel 1983) or oriental knight's-spur (Mansuroglu et al. 2009). Days to first flower decreased linearly with increasing WAT, regardless of PGR treatments. This agrees with Gilbertz (1992) that earlier paclobutrazol spray treated chrysanthemum plants took longer to flower than plants in later treatment. In this study, paclobutrazol drenches did not affect flower longevity, which disagrees with results on 'Lavender' and 'Midget-Red' stock (Ecker et al. 1992) that paclobutrazol drench applications delayed senescence. However, Ecker et al. (1992) applied higher paclobutrazol concentrations (0, 0.25, 0.5 or 2.0 mg per 12 cm (4.7 in) pot.

Based on a survey conducted in a former study using the same quality rating scale as in this study (Chen et al. 2017), plants rated 3 were highly favored as 'the plant you would be most willing to purchase from a garden center' by consumers. However， in this study, untreated plants received more ratings of 3 than plants treated with 1.5 or 3 ppm paclobutrazol because plants were perceived as too small for higher quality ratings. We can't recommend paclobutrazol drenches at the concentrations tested based on unfavorable consumer preferences. Based on the quality rating results, no growth retardant or daminozide applied once at 2500 ppm anytime from 2–6 WAT produced the most marketable plants. However, later PGR application resulted in earlier flowering and greater reductions in peduncle length. Hamrick (2003) recommended 1000–2500 ppm daminozide at 12–14 days after transplanting and another application 10 days later if required. However, in this study, differences in paclobutrazol treatments and daminozide applied twice were similar to those of daminozide applied at 2 weeks, thus a second application was not required in this study.

The effects of PGR treatments on gerbera daisies were different in this study than reported by Chen et al. (2017). They reported that stage of development only affected foliage height of gerbera daisy. However, foliage height was not affected by increasing WAT in this study. Conversely, we found a decrease in peduncle length and DTF with increasing WAT in this study, but reductions in peduncle length and DTF by stages of development were not found in the former study.

Chen el al. (2107) also reported that based on quality rating and survey results, 1 or 2 ppm paclobutrazol drench produced the most marketable plants in fall, and 0, 1, 2, or 3 ppm produced the most marketable plants in spring. These differences may have been because the two studies were conducted in different seasons. Chen el al. (2017) transplanted plants into pots on Sept. 14, 2015 for the fall and on Feb. 4, 2016 for the spring, and the first PGR treatments were applied on Oct. 9 for the fall and Mar. 10 for the spring. In this study, plants were transplanted into pots on Mar. 23, 2016 in the first run and May 9, 2016 in the second run, and the first PGR treatments were applied on Apr. 6 in the first run and May 23 in the second run. Plants may have been exposed to warmer temperatures and higher light intensities at the time of PGR treatment and afterward in this study than in Chen et al. (2017), thus reducing the responses to PGRs.

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Table 4.1. Plant sizes of *Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye' (Mega series) at the time of plant growth retardant treatments 2–6 weeks after transplanting into 12.7 cm (5 in) pots.

	Weeks after transplant					
	2	3	4	5	6	Sign.[z]
Leaf count	3	4	6	9	11	L***
Foliage height[y]	2.8	3.8	6.0	9.5	14.0	Q***
Size index[x]	6.1	8.2	12.1	16.1	22.2	Q***

[z]Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $P < 0.001$ (***).
[y]Foliage height was from the substrate surface to the top of the foliage.
[x]Size index = (foliage height + widest width + width perpendicular to first width) / 3.

Table 4.2. The effects of application timing and substrate drench applications of paclobutrazol (pac) as compared to daminozide (dam) standards on foliage height, size index, and flower diameter of *Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye' (Mega series).[z]

Pac (ppm)	Foliage height (cm)[y]	Size index (cm)[x]	Flower diameter (cm)
0	14.0	30.0	9.9
1.5	10.9	25.8	9.3
3	10.2	24.7	9.3
Significance[w]	Q*	Q**	L**
Dam weekly	12.5	28.0	9.8
Dam once	12.9	29.6	9.8
		Adj Pr[v]	
Dam weekly vs. pac 0 ppm	0.0056	0.0016	0.2656
Dam weekly vs. pac 1.5 ppm	0.0033	0.0006	0.0289
Dam weekly vs. pac 3 ppm	<.0001	<.0001	0.0284
Dam once vs. pac 0 ppm	0.2972	0.7925	0.7392
Dam once vs. pac 1.5 ppm	0.0380	0.0036	0.2234
Dam once vs. pac 3 ppm	0.0046	0.0003	0.2248
Dam once vs. twice	0.9369	0.6238	0.1063

[z]Pac substrate drenches and dam weekly were applied at 2, 3, 4, 5, or 6 weeks after transplanting (WAT) in the first run and at 2, 3, 4, or 5 WAT in the second run. Dam once was from 2 WAT only and dam twice was applied 2 WAT and again 10 days later. Only the plant growth retardant main effects were significant at $P < 0.05$. Responses were measured at first open flower.
[y]Foliage height was from the substrate surface to the top of the foliage.
[x]Size index = (foliage height + widest width + width perpendicular to the first width) / 3.
[w]Significant linear (L) or quadratic (Q) trends using orthogonal polynomials at $P < 0.05$ (*) or 0.01 (**).
[v]Estimated least squares means paired comparisons using the simulated method at $P < 0.05$.

Table 4.3. The effects of application timing and substrate drench application of paclobutrazol (pac) as compared to daminozide (dam) standards on foliage flower stem length and days from transplant to first open flower of *Gerbera jamesonii* Hook. f. ‘Bright Red with Light Eye’ (Mega series).[z]

Pac (ppm)	Peduncle length (cm)[y]	Days from transplant to first open flower[x]	Weeks after potting	Peduncle length (cm)	Days from transplant to first open flower
0	16.8	57	2	17.7	60
1.5	14.5	56	3	15.4	60
3	13.5	59	4	15.5	57
Significance[w]	L***	Q*	5	14.7	55
Dam weekly	16.4	56	6	12.9	54
Dam once	16.7	58	Sign.	L*	L**

	Adj Pr[v]	
Dam weekly vs. pac 0 ppm	0.5890	0.2101
Dam weekly vs. pac 1.5 ppm	0.0025	0.7265
Dam weekly vs. pac 3 ppm	<.0001	0.0025
Dam once vs. pac 0 ppm	0.9312	0.6231
Dam once vs. pac 1.5 ppm	0.0901	0.3336
Dam once vs. pac 3 ppm	0.0145	0.6771
Dam once vs. twice	0.5290	0.8331

[z]Pac substrate drenches and dam weekly were applied at 2, 3, 4, 5, or 6 weeks after transplanting (WAT) in the first run and at 2, 3, 4, or 5 WAT in the second run. Dam once was from 2 WAT only and dam twice was applied 2 WAT and again 10 days later. Only the weeks after potting and plant growth retardant main effects were significant at $P < 0.05$. Responses were measured at first open flower.

[y]Peduncle length was measured from the base of the calyx to the stem’s point of origin at the crown on the first open flower.

[x]A flower was open when the ray floret petals were reflexed perpendicular to the peduncle.

[w]Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $P < 0.05$ (*), 0.01 (**) or 0.001 (***).

[v]Estimated least squares means paired comparisons using the simulated method at $P < 0.05$.

Table 4.4. The effects of application timing and substrate drench application of paclobutrazol (pac) as compared to daminozide (dam) standards on quality rating of *Gerbera jamesonii* Hook. f. 'Bright Red with Light Eye' (Mega series).[z]

	Quality rating level counts			
Weeks after potting	1[y]	2	3	4
2	8	15	28	13
3	12	14	23	15
4	11	15	20	18
5	11	14	22	17
6	1	6	22	7
Significance[x]				L*
Pac (ppm)				
0	8	11	32	22
1.5	15	20	24	14
3	24	21	17	11
Significance				L***
Dam weekly	7	15	32	19
Dam once	0	4	10	2

	Adj Pr[w]
Dam weekly vs. pac 0 ppm	0.5806
Dam weekly vs. pac 1.5 ppm	<.0001
Dam weekly vs. pac 3 ppm	<.0001
Dam once vs. pac 0 ppm	0.9010
Dam once vs. pac 1.5 ppm	0.0201
Dam once vs. pac 3 ppm	0.0001
Dam once vs. twice	0.1224

[z]Pac substrate drenches and dam weekly were applied at 2, 3, 4, 5, or 6 weeks after transplanting (WAT) in the first run and at 2, 3, 4, or 5 WAT in the second run. Dam once was from 2 WAT only and dam twice was applied 2 WAT and again 10 days later. Only the weeks after potting

and plant growth retardant main effects were significant at $P < 0.05$. Response were measured at two or three open flowers.

[y]Quality rating: 1) lower foliage extending 20–30% beyond the pot rim, with tightly spaced, distorted leaves; flowers opened just above foliage on very short peduncles; 2) lower foliage extending 30–50% beyond the pot rim. Leaves less tightly spaced and less distorted than in 1; flowers opened on peduncles that appeared twice as long as in 1; 3) lower foliage extending 60–70% beyond the pot rim; leaves appeared ideal, less tightly spaced than 2, but not as open as 4 with no foliar distortion. Flowers opened on peduncles that appeared four times as long as in 1; 4) plants appeared open and spindly. Lower foliage extending 70–80% beyond the pot rim; leaf spacing open with potting media visible; no leaf distortion; flowers opened on peduncles that appeared six times as long as in 1.

[x]Significant linear (L) trends using orthogonal polynomials at $P < 0.05$ (*) or 0.001 (***).

[w]Estimated paired treatment comparisons. Probability adjusted using the simulated method at $P < 0.05$.

Figure 4.1. Senescence flower