Research Reports

Effect of Plant Growth Regulators on Growth and Flowering of Potted Red Firespike

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SUMMARY. The effect of plant growth regulators (PGRs) on growth and flowering of potted red firespike (*Odontonema strictum*) were examined in two experiments. In Expt. 1, foliar spray applications of daminozide, uniconazole, paclobutrazol, or flurprimidol or media drenches of paclobutrazol or flurprimidol were applied. In Expt. 2, foliar spray application of daminozide or media drenches of paclobutrazol or flurprimidol were further tested for efficacy of height control. Both studies included an untreated control. In Expt. 1, drench applications of paclobutrazol and flurprimidol resulted in plants 65% or 46% to 62% shorter than control, respectively. Paclobutrazol and flurprimidol drenches also decreased overall plant growth by 81% to 88% and 74% to 84%, respectively, compared with the control plants. PGRs did not affect number of inflorescences; however, paclobutrazol and flurprimidol delayed flowering 23 to 31 days. In Expt. 2, plants treated with flurprimidol or paclobutrazol drenches were shorter than the control. The greatest reduction in total plant growth occurred using a flurprimidol drench at 0.47 mg/pot, which resulted in plants 78% smaller than the untreated control. Paclobutrazol and flurprimidol increased the time to flowering 11 to 27 days and 10 to 26 days, respectively. The most attractive and well-shaped plants were achieved with flurprimidol applied at 0.24 mg/pot or applications of paclobutrazol at 0.35 mg/pot.

Red firespike is a vigorous ornamental shrub growing to ≈6 ft in height. It has an upright growth habit and is commonly

cultivated as an ornamental plant in the garden due to its attractive tubular red flowers (Daniel, 1995). The plant has potential for introduction as a flowering potted plant because of its attractive red spikes of flowers and shiny green leaves. However,

without height control, firespike grows too tall, exceeding the commercial requirements for potted plants. Thus, control of firespike stem elongation is necessary to provide an aesthetically balanced, desirable, and marketable product.

PGRs are commonly used as an effective technique to restrict stem elongation to achieve aesthetically and commercially pleasing plants. Most PGRs act by inhibiting different steps during the biosynthesis of gibberellins (GAs) responsible for stem elongation in plants (Rademacher, 2000). In addition to type of PGR, plant height can be influenced by concentration, time of application, number of applications, method of application, formulation, and growing substrate composition (Barrett and Bartuska, 1982; Gilbertz, 1992; Ruter, 1992). The most important issue when using PGRs is determining the most effective application method and concentration for consistent results.

Several PGRs effectively inhibit stem elongation of ornamental plants and influence the time of flowering. The triazole class of PGRs, including flurprimidol, uniconazole, and paclobutrazol, are one of the largest commercially used groups of PGRs. They have been shown to be effective for height control and producing compact plants (Krug et al., 2005; Warner and Erwin, 2003). The triazoles are often more effective than other PGRs in inhibiting GA synthesis, so high concentrations can result in excessive height control and stunted plants (Latimer and Whipker, 2012). Sanderson et al. (1988) compared five application methods of paclobutrazol and reported a substrate drench was the most effective method for controlling plant height. In a study on purple firespike (*Odontonema callistachyum*), plant height was 56% and 46% shorter than the control

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
16.3871	inch ³	cm ³	0.0610
28.3495	oz	g	0.0353
28,350	oz	mg	3.5274 × 10 ⁻⁵
1	ppm	mg·L ⁻¹	1
(°F-32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

using drenches of paclobutrazol and flurprimidol at 3.35 and 1.77 mg/pot, respectively (Rezazadeh and Harkess, 2015). Flurprimidol is effective as a foliar spray or substrate drench for height control (Currey and Lopez, 2011; Krug et al., 2005). Daminozide is not a triazole but rather suppresses plant height by reducing the conversion of GA to active forms of GA and reducing translocation of GA to actively growing tissues (Rademacher, 1991). Whipker and Dasoju (1998) reported that spray application of daminozide at 4000 to 8000 ppm resulted in marketable size potted sunflower (*Helianthus annuus*) plants.

Specific PGR recommendations for red firespike have not been previously described. This study was conducted to determine the efficacy of flurprimidol, paclobutrazol, uniconazole, and daminozide PGRs on the growth and flowering of potted red firespike.

Materials and methods

Vegetative stock plants of red firespike were maintained under long days to prevent floral initiation occurring before starting the experimental treatments. In Jan. 2014, medial, single-node cuttings of red firespike were rooted. Four weeks later, the rooted cuttings were transplanted to 6-inch-diameter pots containing a commercial potting substrate (Sunshine Mix 1; Sun Gro Horticulture, Bellevue, WA) and grown under natural daylength in a double-layered polyethylene covered greenhouse. One plant was grown per container. Greenhouse air temperature set points were 64/74 °F (night/day). The plants were fertigated using 200 ppm nitrogen from a 20N-4.4P-16.6K liquid fertilizer (Peters Peat-Lite 20-10-20; Scotts, Marysville, OH). Plants were pinched 2 weeks after transplanting leaving two to three nodes. PGRs were applied when the new axillary shoots were 3 to 5 cm long (≈ 14 d after pinching).

In the first experiment, four PGRs at various rates were tested including: flurprimidol (Topflor; SePRO Corp., Carmel, IN) foliar spray application at 45, 60, or 80 ppm a.i. or a substrate drench at 0.24, 0.47, or 0.71 mg/pot a.i.; paclobutrazol (Bonzi; Syngenta Crop Protection, Greensboro, NC) foliar spray at 10,

20, 40, 60, 80, or 100 ppm a.i. or a substrate drench at 0.59, 1.20, or 1.77 mg/pot a.i.; uniconazole (Sumagic; Valent USA Corp., Walnut Creek, CA) foliar spray at 20, 30, or 45 ppm a.i.; and foliar sprays of daminozide (Dazide; Fine Americas, Walnut Creek, CA) at 2500 ppm a.i. applied three times or 5000 ppm a.i. applied two times at 2-week intervals.

In the second experiment starting 19 June 2014, red firespike cuttings were rooted as previously described. Rooted cuttings were transplanted to 6-inch-diameter pots. Plants were pinched 2 weeks after transplanting leaving two to three nodes. The greenhouse temperature set points were 64/74 °F (night/day). Plants were irrigated and fertilized as in the first experiment. Foliar spray applications of daminozide at 8,000, 10,000, 10,000 2 $\times$ (applied twice at 2-week intervals), or 15,000 ppm; paclobutrazol substrate drenches at 0.30 mg/pot applied twice, 0.35, 0.47, or 0.59 mg/pot; or flurprimidol substrate drenches at 0.24 mg/pot, 0.24 mg/pot applied twice, 0.35 mg/pot, or 0.47 mg/pot were applied when the new axillary shoots were 3 to 5 cm long. Both studies included an untreated control. In both experiments, plants of similar size were selected for uniformity before the PGRs were applied.

A complete randomized design with treatments replicated 10 times was used for both experiments. At the end of each experiment (20 weeks after sticking cuttings), final plant height (from the soil level to the top point of the plant), width (the average of the width measured at the widest point of the plant and 90° to the widest point), growth index [$GI = \pi \times (\text{average width}/2)^2 \times \text{height}$], total leaf area (LI-3100 area meter; LI-COR, Lincoln, NE), total plant dry weight, number of inflorescences, length of inflorescences from the base of the peduncle to the terminus, and days from date of sticking the cutting to first visible flower bud were recorded. Days to flowering were calculated from sticking the cutting to the date when the first immature inflorescence was observed (i.e., visible bud). Data were analyzed using the GLM procedure of SAS (version 9.3; SAS Institute, Cary, NC) to determine the efficacy of the PGRs

on growth and flowering of firespike. Means were separated using the least significant difference test at $P \leq 0.05$.

Results and discussion

EXPT. 1. All substrate drench applications of paclobutrazol and flurprimidol effectively limited stem elongation and thus final plant height of red firespike (Table 1). Maximum height control was obtained with paclobutrazol or flurprimidol drenches, resulting in plants 65% or 46% to 62%, respectively, shorter than the untreated control. However, high concentrations of paclobutrazol and flurprimidol drench resulted in excessive height control negatively affecting plant aesthetics. Although spray applications of daminozide, paclobutrazol, and flurprimidol resulted in plants shorter than the control, there were no differences within PGR in final plant height due to spray application concentration (Table 1). Previous studies reported drench applications of paclobutrazol were more effective than foliar sprays (Cox and Keever, 1988; Cramer and Bridgen, 1998) as was also observed in this study. Plant width followed a similar pattern where the greatest reduction in plant width was observed in plants treated with paclobutrazol or flurprimidol drenches. Plant width tended to decrease as paclobutrazol or flurprimidol drench concentration increased (Table 1).

Comparing the GI, all PGRs were effective at limiting plant growth compared with the control. The decrease in GI was related to both restricted plant height and width following PGR application. Drench applications of paclobutrazol or flurprimidol were particularly effective in limiting growth. Paclobutrazol and flurprimidol drenches decreased the GI by 81% to 88% and 74% to 84%, respectively, compared with control plants (Table 1); however, the highest concentrations excessively limited plant growth and resulted in aesthetically unpleasant plants. Only the highest concentrations of uniconazole, paclobutrazol, and flurprimidol sprays and the paclobutrazol and flurprimidol drenches effectively restricted leaf expansion (Table 1). It was also observed that plants drenched with paclobutrazol or flurprimidol had

Table 1. Plant final height, width, growth index [$GI = \pi \times (\text{average width}/2)^2 \times \text{height}$], leaf area, dry weight, inflorescence number, inflorescence length, and days to flowering (from sticking cuttings to first visible flower bud) in red firespike were measured following spray or drench applications of daminozide, uniconazole, paclobutrazol, or flurprimidol.

Treatment	Rate ²	Method	Plant ht (cm) ^y	Plant width (cm)	GI (cm ³) ^y	Leaf area (cm ²) ^y	Plant dry wt (g) ^y	Inflorescence (No.)	Inflorescence ht (cm)	Time to flower (d)
Control			59.5 a ^x	39.7 a	72,314 a	3,710 a	50 a	3.3 ab	33.0 a	128 g
Daminozide	2,500 3×	ppm	45.5 c	36.0 a-e	46,733 d-f	3,103 a-d	47 a-c	3.0 ab	19.2 b-d	129 g
	5,000 2×	ppm	46.5 bc	35.0 a-e	45,044 f	3,399 a-c	48 ab	3.3 ab	26.7 ab	131 g
Uniconazole	20	ppm	46.7 bc	34.8 c-e	44,106 f	3,384 a-c	45 a-d	3.2 ab	23.2 b-d	131 fg
	30	ppm	47.7 bc	39.2 ab	57,036 b-d	3,238 a-d	44 b-e	3.0 ab	23.8 bc	133 fg
	45	ppm	57.2 a	37.0 a-d	60,027 b	2,986 b-d	44 b-e	2.5 b	17.3 cd	135 e-g
Paclobutrazol	10	ppm	47.7 bc	39.7 a	58,192 bc	3,253 a-d	47 a-c	3.3 ab	22.5 b-d	136 e-g
	20	ppm	50.0 bc	34.0 c-e	45,142 f	3,306 a-c	45 a-d	3.0 ab	26.7 ab	137 d-g
	40	ppm	51.2 b	38.0 a-c	57,369 bc	3,062 a-d	46 a-d	3.3 ab	23.2 b-d	137 d-g
	60	ppm	50.8 b	34.2 c-e	45,623 f	3,044 a-d	42 de	3.7 a	23.8 bc	136 e-g
	80	ppm	50.7 bc	33.5 de	45,100 f	3,635 ab	47 a-d	3.0 ab	19.8 b-d	137 d-g
	100	ppm	49.7 bc	32.0 e	39,697 f	2,765 c-e	42 de	3.7 a	26.3 ab	138 e-g
	0.59	mg/pot	24.0 e	27.0 fg	13,491 g	2,627 d-f	42 c-e	2.7 bc	20.1 b-d	148 a-e
	1.2	mg/pot	21.8 e	23.0 gh	9,413 g	1,976 f-h	35 gf	1.8 cd	19.8 b-d	150 a-e
	1.77	mg/pot	20.7 e	22.7 h	8,435 g	1,309 h	31 g	1.3 d	18.5 b-d	151 a-c
Flurprimidol	45	ppm	49.7 bc	34.8 c-e	47,745 c-f	3,190 a-d	46 a-d	3.3 ab	25.8 a-c	135 e-g
	60	ppm	51.5 b	35.0 b-c	50,398 b-e	3,174 a-d	45 a-e	3.7 a	24.0 bc	136 e-g
	80	ppm	49.5 bc	33.2 de	42,504 ef	2,975 b-d	44 b-e	3.0 ab	23.5 bcd	137 defg
	0.24	mg/pot	31.8 d	27.5 f	18,361 g	2,259 e-g	39 ef	2.7 bc	23.5 bcd	144 bcdef
	0.47	mg/pot	22.7 e	23.2 gh	9,290 g	1,762 gh	33 g	1.8 cd	19.8 bcd	151 ab
	0.71	mg/pot	23.5 e	23.5 fgh	11,253 g	1,819 gh	31 g	1.2 d	15.0 d	159 a

²2x or 3x represents two or three applications applied at 2-week intervals; 1 ppm = 1 mg/L⁻¹; 1 mg = 3.5274 × 10⁻⁵ oz, 1 cm = 0.3937 inch; 1 cm³ = 0.0610 inch³; 1 cm² = 0.1550 inch²; 1 g = 0.0353 oz.

^xMeans within a column followed by the same letter are not significantly different according to the Fisher's protected least significant difference means comparison test at $P = 0.05$.

shorter internodes and thicker, darker green leaves (data not shown). Thakur et al. (2006) showed that PGRs can increase chlorophyll content in the leaves and promote the formation of darker green leaves.

Total plant dry weight was less than the control in treatments receiving spray applications at ≥ 30 ppm uniconazole, 60 or 100 ppm paclobutrazol, or 80 ppm flurprimidol. Paclobutrazol drenches ≥ 1.2 mg/pot and all rates of flurprimidol drenches were more effective in reducing plant dry weight than spray applications of all tested PGRs and the control (Table 1). Decreases in leaf area and dry weight after PGR applications have also been reported in cucumber [*Cucumis sativus* (Cho et al., 2002)] and purple firespike (Rezazadeh and Harkess, 2015).

There were no differences in number of inflorescences among plants sprayed with PGRs and control plants; however, drench applications of paclobutrazol and flurprimidol decreased inflorescence numbers. Minimum inflorescence numbers were recorded in plants drenched with paclobutrazol at 1.2 or 1.77 mg/pot or flurprimidol at 0.47 or 0.77 mg/pot (Table 1). These results agree with a previous study where paclobutrazol reduced the number of flowers in fuchsia [*Fuchsia magellanica* (Gad et al., 1997)], but do not agree with Song and Lee (1995) who reported an increased number of inflorescences in Japanese camellia (*Camellia japonica*) drenched with paclobutrazol. As with plant height, PGRs affected inflorescence length with the maximum inflorescence length obtained in the control. Most PGR treatments restricted inflorescence elongation with the effect increasing as PGR concentration increased. The shortest inflorescences were recorded on plants treated with the highest drench concentrations of paclobutrazol or flurprimidol (Table 1).

The time to flower (visible bud) increased by 23 to 31 d in plants drenched with paclobutrazol or flurprimidol at 1.77 or 0.71 mg/pot, respectively, compared with the control. Foliar sprays of daminozide, paclobutrazol, flurprimidol, or uniconazole did not delay flowering. Delay or inhibition of flowering following

Table 2. Plant final height, width, growth index [$GI = \pi \times (\text{average width}/2)^2 \times \text{height}$], leaf area, dry weight, branch number, inflorescence number, inflorescence length, and days to flower (from sticking cuttings to first visible flower bud) in red firespike were measured following spray or drench applications of daminozide, paclobutrazol, or flurprimidol.

Treatment	Rate ²	Method	Plant ht (cm) ³	Plant width (cm)	GI (cm ³) ³	Leaf area (cm ²) ³	Plant dry wt (g) ³	Inflorescence (No.)	Inflorescence ht (cm)	Time to flower (d)
Control			57.8 a ³	30.8 a	43,258 a	9,320 a	32 ab	2.8 a-c	29.7 a	108 f
Daminozide	8,000	ppm	45.8 bc	27.8 a-c	29,309 bc	3,236 b	29 a-c	2.3 bc	22.8 a-d	110 ef
	10,000	ppm	55.0 ab	29.0 a-c	36,401 ab	3,454 ab	29 a-c	2.7 a-c	23.8 a-c	113 d-f
	10,000 2×	Spray	39.0 cd	26.3 b-f	21,253 c-e	2,822 c	25 cd	1.7 c	17.3 c-e	115 d-f
	15,000	Spray	54.0 ab	30.8 a	41,889 a	2,398 d	33 a	3.5 ab	27.8 ab	115 d-f
Paclobutrazol	0.3 2×	mg/pot	33.8 de	30.2 ab	23,741 cd	1,979 e	25 c	2.7 a-c	27.3 ab	119 cd
	0.35	mg/pot	26.8 ef	26.0 c-f	14,592 d-f	2,146 de	27 bc	2.5 a-c	20.7 b-e	121 b-d
	0.47	mg/pot	36.5 c-e	28.3 a-d	24,030 cd	2,096 de	26 c	2.3 bc	23.3 a-d	130 ab
	0.59	mg/pot	31.6 d-f	28.7 a-c	20,479 c-e	1,353 f	26 c	3.5 ab	24.8 a-c	135 a
Flurprimidol	0.24	mg/pot	29.8 d-f	25.0 c-f	14,491 d-f	2,029 e	33 a	3.0 ab	15.5 de	118 c-e
	0.24 2×	mg/pot	21.5 f	24.5 d-f	10,774 ef	2,262 de	20 d	3.7 a	22.3 a-d	130 ab
	0.35	mg/pot	26.7 ef	23.8 ef	12,611 ef	2,196 de	26 c	3.0 ab	21.0 b-d	125 bc
	0.47	mg/pot	21.5 f	23.7 f	9,320 f	1,519 f	25 c	3.3 ab	12.5 e	134 a

²2× represents two applications applied at 2-week intervals; 1 ppm = 1 mg·L⁻¹; 1 mg = 3.5274 × 10⁻⁵ oz.

³1 cm = 0.3937 inch; 1 cm³ = 0.0610 inch³; 1 cm² = 0.1550 inch²; 1 g = 0.0353 oz.

⁴Means within a column followed by the same letter are not significantly different according to the Fisher's protected least significant difference means comparison test at $P = 0.05$.

PGR application has been reported in sunflower (Dasoju et al., 1998) and bleeding heart [*Dicentra spectabilis* (Kim et al., 1999)].

EXPT. 2. Spray applications of paclobutrazol, flurprimidol, or uniconazole provided minimal height control of red firespike in Expt. 1 and were not included in Expt. 2. Paclobutrazol and flurprimidol drenches and daminozide sprays were examined at lower rates in Expt. 2. Daminozide applied twice at 10,000 ppm resulted in plants 18.8 cm shorter than untreated plants (Table 2). The increased rates of daminozide required to affect height may make use of this PGR impractical. Plants were shorter than the control after treatment with paclobutrazol and flurprimidol drenches, which provided the most height control (Table 2). However, excessive dwarfing occurred when plants received 0.24 to 0.47 mg/pot flurprimidol or 0.35 or greater mg/pot paclobutrazol (Table 2). All rates of flurprimidol drenches excessively restricted plant width compared with untreated control plants (Table 2). Paclobutrazol or daminozide had less effect on plant width and were similar in width to the control at most rates.

Compared with the control plants, overall plant size, as represented by GI, was considerably smaller following applications of paclobutrazol or flurprimidol. GI was least when using flurprimidol drenches resulting in plants up to 78% smaller than the untreated control. The low GI following flurprimidol application was due to a greater restriction in plant height and width than other treatments. Leaf area was also greatly affected by paclobutrazol and flurprimidol drenches with less leaf area than the control (Table 2). Daminozide sprays had a lesser effect, but the higher rates were effective in reducing leaf area. Plants treated with flurprimidol or paclobutrazol drenches had shorter internodes and thicker, darker green leaves (field observations, data not collected) likely due to the concentration of chlorophyll into smaller leaf cells (Fletcher et al., 2010; Thakur et al., 2006). High rates of paclobutrazol or flurprimidol drenches decreased plant dry weight, which coincided with the shorter height and reduced GI.

There were no differences in the number of inflorescences between PGRs or the control. This result is consistent with previous studies, which reported no effect of PGRs on flower number (Jiao et al., 1990; Sanderson et al., 1989; Simmonds and Cumming, 1977). Inflorescence length was 12 cm shorter than the control when using daminozide at 10,000 ppm applied twice. Single flurprimidol drenches at 0.24, 0.35, or 0.47 mg/pot resulted in shorter inflorescence lengths than the control. A study on 'Prima' asiatic hybrid lily (*Lilium*) also showed a decrease in flower size following flurprimidol applications (Pobudkiewicz and Nowak, 1992). Daminozide only reduced inflorescence height compared with the control when applied in multiple applications of 10,000 ppm (Table 2).

Daminozide sprays did not increase the days to flower (time to visible bud). Paclobutrazol and flurprimidol drenches, however, increased the days to flowering: an effect that increased as paclobutrazol or flurprimidol concentration increased (Table 2). The increased time to flowering when using paclobutrazol was also reported in stock [*Matthiola incana* (Ecker et al., 1992)], tulip [*Tulipa gesneriana* (McDaniel, 1990)], and red flag bush [*Mussaenda erythrophylla* (Cramer and Bridgen, 1998)]. However, 'Mustang' geranium (*Pelargonium ×hortorum*) treated with paclobutrazol spray or drench flowered earlier than control plants (Cox, 1991). Flurprimidol delayed flowering in geranium (Pobudkiewicz, 2000) and chrysanthemum [*Dendranthema grandiflora* (Pobudkiewicz and Nowak, 1997)] and had no effect on time to anthesis in dwarf carnation [*Dianthus caryophyllus* (Pobudkiewicz and Nowak, 1994)]. Delayed flowering may be due to persistence of these compounds in the plant tissues. Delayed flowering following increasing PGR concentrations was reported on 'Prima' asiatic hybrid lily (Pobudkiewicz and Nowak, 1992) and in 'Nellie White' easter lily [*Lilium longiflorum* (Bailey and Miller, 1989)].

Flurprimidol and paclobutrazol drenches had the greatest effect on restricting plant height in red fire-spike. However, high concentrations of both PGRs resulted in excessive

height control, which was not within the target range for finished plant height. Both of these PGRs produced long-lasting and uniform results, which could be due to binding of the growth retardants to the organic media components and release over several weeks (Boldt, 2008; Currey and Lopez, 2011). Daminozide provided less growth control of red fire-spike and required excessively high concentrations to control growth. Spray applications of paclobutrazol, uniconazole, and flurprimidol were not as effective as substrate drenches of paclobutrazol and flurprimidol for growth regulation. Aesthetically balanced potted plants of red firespike were achieved when flurprimidol at 0.24 mg/pot or paclobutrazol at 0.35 mg/pot were used.

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