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Response of 'Foxy' Foxglove to GA_3 and Cold Treatment[1]

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Abstract

A single foliar spray of 10–50 ppm GA_3 promoted earlier (up to 30 days), more uniform flowering with higher flower counts per inflorescence in 'Foxy' foxglove. Treated plants were compact with attractive foliage and considered marketable. Plants treated with higher rates of GA_3 (75–1,000 ppm) formed excessively elongated inflorescences with malformed flowers and thin, strap-like, light green foliage. Cold treatment at 4.4C (40F) for 4 weeks shortened time to flower 8 and 6 days compared to that of plants cooled for 0 and 2 weeks, respectively. In the absence of GA_3, cold treatment increased the number of inflorescences compared to plants not cooled.

Index words: gibberellic acid, growth regulator, biennial, cold treatment, vernalization.

Species used in this study: 'Foxy' foxglove (*Digitalis purpurea* L. 'Foxy').

Growth regulator used in this study: Pro-Gibb (gibberellic acid, GA_3).

Significance to the Nursery Industry

Flowering in 'Foxy' foxglove is often sporadic and even when seeds are sown at the appropriate time, peak marketability is often not obtained during spring. A single foliar application of 10–50 ppm GA_3 can promote earlier (up to 30 days), more uniform flowering with higher flower bud counts; however, plants may be taller than untreated plants. GA_3 rates of 75 ppm were detrimental to plant quality. A 4-week cold treatment shortened time to flower 7 days and doubled the number of inflorescences compared to non-cooled plants. However, the combination of cooling and GA_3 treatment reduced the number of inflorescence at first flower compared to that of plants only cooled. These results may aid growers in scheduling flowering plants of 'Foxy' foxglove to meet their marketing windows.

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Introduction

Foxgloves, *Digitalis purpurea* L., are known for their stately spikes of color in shades of purple, pink or white. Being true biennials or weak perennials, foxgloves rosette the first season from seed and bloom the next spring. For spring flowering plants, foxglove can be sown the previous year until November and grown cold, but not dormant, during the winter. Flowering is often sporadic during late spring and early summer. However, foxglove often lives through one more winter and flowers more profusely the following spring (8).

One variety, 'Foxy', flowers as an annual if started early enough from seed. Production guides for 'Foxy' suggest seed be sown in December or January for flowering plants in May and June (7). This period is past the peak spring marketing period in the Southeastern United States, and flowering in 'Foxy' may be non-uniform, further reducing marketability. While earlier sowing may address the late flowering problem, other cultural practices may shorten cropping time and improve uniformity of flowering.

Gibberellins (GA), including GA_3 and GA_{4+7}, have been used to accelerate flowering and enhance uniformity of flowering in numerous horticultural crops (4, 5, 6, 9, 10, 11). Another option is to expose plants to a period of low temperature prior to forcing into flower. Cold treatment, or vernalization, is a requirement for biennials, including *D. purpurea*, and many herbaceous perennials before they are capable of flowering (1, 3) but not for 'Foxy' (8). However, many herbaceous perennials not requiring vernalization flower earlier and more uniformly when exposed to a cold treatment (1, 2, 3). The objective of this research was to determine the effects of GA_3 application and cold treatment on flowering in 'Foxy' foxglove. The overall goal was to accelerate flowering and enhance uniformity of flowering without reducing plant quality.

Materials and Methods

Experiment 1. Uniform, seed-grown liners of 'Foxy' foxglove obtained from a commercial grower were transplanted on May 23, 1994, from 36-cell packs into 12.7 cm (5 in) pots containing a commercial peat-based medium (Growing Mix No. 2, Conrad Fafard, Agawam, MA). Containers were placed on 61 cm (24 in) centers in an unshaded double-layer polyethylene greenhouse with heat and ventilation setpoints of 18.3C (65F) and 25.6C (78F), respectively. Plants were fertilized 3 times per week with 250 ppm N from 20N–4.3P–16.6K (20–10–20) Peters Peatlite Special (The Scotts Co., Marysville, OH) beginning at potting and continuing until June 14, when fertilization was reduced to twice per week. Water was applied at other times as needed. On July 1, single foliar sprays of 0, 10, 25, 50, 100, 125, 250, 500, 750, or 1,000 ppm GA_3 (Pro-Gibb, Abbott Laboratories, N. Chicago, IL) were applied in a volume of 204 ml/m^2 (2 qt/100 ft^2) to plants. Buffer-X (Kalo Agr. Chemicals, Overland Park, KS) at 0.2% was added to all GA_3 solutions as a surfactant. Application was made with a CO_2 sprayer fitted with a cone nozzle at 138 kPa (20 psi). Temperature and relative humidity at the time of application were 26.7C (80F) and 87%, respectively. When treated, plants had a mean leaf count of 16.8, a height of 17.3 cm (6.8 in), and a growth index [(height + width at the widest point + width perpendicular to the first width) ÷ 3] of 28.7 cm (11.3 in). On July 22, 47% shadecloth was placed over benches to reduce plant water needs. Treatments were completely randomized with 10 single-plant replications. At the time of the first opened flower, date, height from the substrate surface to the highest point, growth index, foliar color rating (1, 3, and 5 = light, medium and dark green, respectively) and number of inflorescences were recorded. The experiment was terminated 150 days after treatment (DAT) and non-flowering plants noted. Rate responses to GA_3 were determined by single degree of freedom orthogonal contrasts.

Experiment 2. Methodology in the second experiment was the same as that in the first experiment unless stated otherwise. One hundred and twenty uniform liners of 'Foxy' foxglove were transplanted on November 18, 1994, from 36-cell packs into 3.8 liter (#1) pots containing Fafard No. 2 medium. Containers were placed in an unshaded, double-layer polyethylene greenhouse under natural photoperiod and fertilized twice per week while in the greenhouse. Three low temperature durations (0, 2 or 4 weeks) were evaluated by placing 40 plants each in a dark cooler at 4.4C (40F) on January 20 and February 3, 1995; 40 plants remained in the greenhouse. On February 17, cooled plants were returned to the greenhouse and on the following day, single foliar sprays of 0, 16.7, 33.3 or 50 ppm GA_3 were applied to 10 plants from each of the 3 low temperature groups. Spray rates were based on results of the first experiment. Temperature and relative humidity at the time of application were 18.8C (66F) and 90%, respectively. Mean height, growth index and leaf count of 5 representative plants were 23.6 cm (9.2 in), 33.6 cm (13.2 in) and 13.2 for non-cooled plants, 17.2 cm (6.8 in) , 28 cm (11 in), and 9.6 for plants cooled 2 weeks, and 16 cm (6.3 in), 23.9 cm (9.4 in) and 8.8 for plants cooled 4 weeks., respectively. Treatments in this 3 × 4 factorial experiment (cooling × GA_3) were arranged in a completely randomized design with 10 single-plant replications. When the first flower opened, date, growth index, number of inflorescences, flowers per inflorescence and a quality rating (1–5 where 1 = excessive inflorescence elongation, strap-like leaves and/or

Table 1. Response of foxglove to gibberellic acid (GA_3), experiment 1.

GA_3 rate (ppm)	Days to flower	Flowering (%)	Height[z] (cm)	Growth index[y] (cm)	Foliar color rating[x]
Control	61	30	28.7	43.0	3.6
10	56	70	31.4	44.8	3.9
25	58	100	32.3	41.4	4.4
50	57	100	35.8	43.9	4.0
75	50	100	50.9	52.1	4.2
100	49	100	48.8	49.0	4.2
125	53	100	48.4	52.0	3.2
250	49	100	51.8	53.2	3.7
500	54	100	48.1	48.7	3.5
750	52	100	52.7	53.8	3.7
1,000	55	100	49.0	51.3	2.7
Significance[w]	NS		L***Q***	L***Q***	L***

[z]Height measured from the medium surface to the top of the inflorescence.

[y]Growth index = (height + widest width + width 90° to first width) ÷ 3.

[x]Foliar color rating: 1, 3 and 5 = light, medium and dark green, respectively.

[w]NS, L, Q: nonsignificant, linear, or quadratic response, respectively, at the 0.001 level (***); control included in the regression analysis.

Table 2. Response of foxglove to gibberellic acid (GA_3), experiment 2.

GA_3 rate (ppm)	Days to flower[z]	Flowers per inflorescence	Height[y] (cm)	Growth index[x] (cm)	Quality rating[w]
Control	95	15.4	60.9	55.5	4.6
16.7	66	24.3	77.6	61.2	3.7
33.3	62	25.1	92.6	67.9	3.5
50.0	67	24.2	82.2	61.8	3.2
Contrast[v]					
Control vs. GA_3	***	***	***	**	***
Significance[u]	NS	NS	L*Q***	L*Q***	L**

[z]Days from GA_3 application to first open flower.

[y]Height from the medium surface to the top of the inflorescence measured at first open flower.

[x]Growth index = (height + widest width + width 90° to first width) ÷ 3; measured at first open flower.

[w]Quality rating: 1–5 where 1= excessive inflorescence elongation, strap-like leaves and/or foliar chlorosis; 3 = inflorescence elongation but height to plant width and container size acceptable, elliptical leaves, and/or medium green foliage; and 5 = excellent height to plant width and container size, elliptical leaves, and/or dark green foliage.

[v]Single degree of freedom contrast significant at P = 0.01 (**) or 0.001 (***).

[u]NS, L, Q: Nonsignificant, linear, or quadratic response, respectively, at P = 0.05 (*), 0.01 (**), or 0.001 (***); control not included in regression analysis, and GA_3 × cooling interactions nonsignificant.

foliar chlorosis; 3 = acceptable height to plant width and container size, elliptic leaves and/or medium green foliage; and 5 = excellent height to plant width and container size, elliptic leaves and/or dark green foliage) were recorded. Also, individual flowers were monitored from opening to senescence of the corolla to determine flower longevity. The experiment was terminated 144 DAT and non-flowering plants noted. Main effects and interactions were tested by an analysis of variance. Main effects only were reported when interactions were not significant. Single degree of freedom orthogonal contrasts were used to compare among cooling levels and to compare non-GA_3 controls to GA_3 treatments. Regression analysis was used to test rate response to GA_3.

Results and Discussion

Experiment 1. Days to the first open flower (DTF) was not significantly affected by treatments although there was a trend for earlier flowering with GA_3 treatment (control = 61 DTF, treated = 53 DTF, Table 1). Only plants that flowered were included in the DTF analysis; 30% for controls, 70% for plants treated with 10 ppm GA_3, and 100% for all other treatments. The low % flowering in control plants may in part account for the lack of significance for DTF. Enhanced flowering in foxglove with gibberellin application concurs with previous research using other herbaceous species (5, 6, 9, 10, 11). Plant height and growth index responses at first flower to increasing GA_3 rate were quadratic. Heights were similar for controls and plants treated with 50 ppm GA_3, and inflorescence lengths were considered proportional to plant and pot sizes. Heights of plants treated with 75 ppm GA_3 averaged 50.0 cm or 74% more than those of controls. Inflorescences of plants treated with these higher rates of GA_3 were excessively elongated relative to plant and pot sizes. Flowers on plants treated with 100 ppm GA_3 were malformed or incompletely developed, while on plants treated with > 100 ppm GA_3 there appeared to be fewer flowers per inflorescence, and flowers appeared to senesce sooner. Excessive floral scape elongation and flower distortion have been reported in other crops treated with GA_3 (9, 11). The number of inflorescences per plant was not affected by treatment (data not shown).

Foliar color rating decreased linearly with increasing GA_3 rate although ratings for plants treated with 100 ppm were numerically similar. Distinct differences in appearance occurred between plants treated with 50 ppm and those treated with 75 ppm. Lower rates produced compact plants with thick, coarse and elliptical-shaped leaves. Higher rates produced less compact plants with thinner, more elongated leaves.

Overall, GA_3 rates of 10–50 ppm promoted flowering (70–100%) compared to 30% for untreated controls. In addition, these plants were compact with attractive foliage and were considered highly marketable. Foxglove treated with higher rates of GA_3 flowered but many of the flowers were malformed or incompletely developed and inflorescences were excessively elongated. Also, leaves were thinner, strap-like, and noticeably lighter green.

Experiment 2. DTF was affected by GA_3 and cold but the interaction was not significant. GA_3-treated plants flowered an average of 30 days earlier than controls, but GA_3 rate had no effect on DTF (Table 2). Accelerated flowering with GA_3 application is well documented in other crops (4, 9, 10, 11), but has not been reported in foxglove. Cooling plants for 4 weeks prior to forcing also accelerated flowering: 67 DTF vs. 75 and 73 DTF for 0 and 2 weeks of cold, respectively ($P \leq 0.001$). Cold treatment as a main effect was not significant for any of the other attributes measured. Flowering in GA_3 controls cooled for 0 and 2 weeks was 90% and 60%, respectively, and 80% in non-cooled plants treated with 16.7 ppm GA_3, while 100% of plants in all other treatments flowered. Higher flowering percentages with GA_3 application agrees with results from the first experiment. Although not compared statistically due to experimental design, cooling for 4 weeks appeared to enhance flowering (100% vs. 90 % and 60% for 0 and 2 weeks, respectively) in the absence of GA_3 application.

The number of inflorescences was influenced by a GA_3 × cooling interaction (Table 3). In the absence of cooling, GA_3 had no effect on the number of inflorescences, a similar re-

Table 3. Number of foxglove inflorescences as influenced by gibberellic (GA_3) acid and cooling, experiment 2.

Cooling duration (wk)	GA_3 (ppm)				Control vs. GA_3[z]	Significance[y]
	Control	16.7	33.3	50.0		
0	2.1	2.4	1.0	1.8	NS	NS[y]
2	3.3	1.9	1.0	1.0	**	NS
4	4.4	1.0	1.2	1.0	***	NS
Significant contrasts						
0 vs. 2	NS	NS	NS	NS		
0 vs. 4	**	NS	NS	NS		
2 vs. 4	NS	NS	NS	NS		

[z]Single degree of freedom contrast nonsignificant (NS) or significant at P = 0.01 (**) or 0.001 (***); GA_3 × cooling interaction significant at P = 0.05.
[y]Regression response nonsignificant (NS); control not included in regression analysis.

sponse to that observed in the first experiment. When plants were cooled 2 or 4 weeks, GA_3 decreased the number of inflorescences relative to that of the controls but there was no rate effect. Among GA_3 controls, plants cooled for 4 weeks formed more inflorescences than those not cooled. Cooling duration had no effect on the number of inflorescences in plants treated with GA. GA_3-treated planted produced an average of 59% more flowers per inflorescence than controls (Table 2), but there was no rate effect of GA_3. Flower longevity was not affected by GA_3 or cooling (data not shown).

GA_3-treated plants were an average of 38% taller than controls. Height in response to GA_3 rate increased up to 33.3 ppm before declining at 50 ppm. Growth index followed a similar, though less pronounced response to GA_3; growth index of GA_3-treated plants was an average of 14.7% higher than that of controls. Flowering plants in the second experiment were noticeably taller than plants receiving similar rates of GA_3 in the first experiment. This condition possibly resulted from the shorter day lengths and lower light levels during the second experiment or the larger containers used for cropping.

Quality rating was higher for control plants than for plants treated with GA_3, primarily due to more elongation of the inflorescence in GA_3-treated plants. This trend is reflected in height data. Although GA-treated plants were taller and the quality rating lower, heights of these plants were proportional to plant width and pot size and plants were considered marketable.

Based on results of these two experiments, application of 10–50 ppm GA_3 offers potential benefits in the production of 'Foxy' foxglove. Plants treated with GA_3 in this range flowered earlier and more uniformly with higher flower counts per inflorescence, which translates into less bench time. These plants had attractive foliage and were considered marketable. All foxglove treated with higher rates of GA_3 flowered but many of the flowers were malformed, inflorescences were excessively elongated, and leaves were thinner, strap-like, and noticeably lighter green. Cooling plants for 4 weeks shortened DTF compared to that of plants cooled for 0 or 2 weeks, and in the absence of GA_3, increased the number of inflorescences compared to plants not cooled.

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