Foliar Applications of GA₄₊₇ Reduce Flowering in Highbush Blueberry

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Abstract. Precocious varieties of highbush blueberry (*Vaccinium corymbosum* L.) may overcrop during the first few seasons in the fruiting field, adversely affecting plant establishment. Reducing or preventing bloom in the nursery and during establishment would be beneficial in preventing early cropping and reducing the risk of infection by pollenborne viruses. We investigated the efficacy of foliar applications of GA₄₊₇ for suppressing flower bud initiation in blueberry. One-year-old rooted cuttings of 'Bluecrop' were obtained from a commercial nursery and established in 11-L pots at the Philip E. Marucci Blueberry and Cranberry Research Center, Chatsworth, N.J. Three separate experiments were conducted over three seasons with 'Bluecrop' (and 'Duke' in 2005) highbush blueberry where foliar applications of GA₄₊₇ were made at concentrations ranging from 50 to 400 mg·L⁻¹ a.i., with timing treatments ranging from 7 July to 15 Sept., with 10 replicate plants per treatment. Floral and vegetative buds were counted the following spring. In the first study, the greatest degree of flower bud suppression resulted from applications at 400 mg·L⁻¹ repeated weekly from 7 July to 1 Sept. However, these treatments also reduced total vegetative bud number and plant height. In the two subsequent studies, the largest treatment effect resulted from three weekly applications in late August and early September, where flower bud numbers were suppressed by 70% to 85% for 'Bluecrop' and 95% for 'Duke' while total vegetative growth was unaffected.

Blueberry plants are susceptible to several pollenborne viral diseases, including Blueberry Shock and Blueberry Leaf Mottle Disease (Pritts and Hancock, 1992). Nurseries go to great lengths to ensure that blueberry plants remain virus-free to meet quarantine restrictions and to prevent distributing infected plants. In addition to starting with tissue culture plantlets indexed for shock-causing virus, nurseries carry out extensive pruning and flower bud removal to prevent bloom, thereby eliminating potential infection sites (Brazelton, personal communication).

Some varieties of highbush blueberry are relatively precocious, producing significant crops during the first few years in the field.

Recently, Strik and Buller (2005) reported that allowing the cultivars Duke, Bluecrop, and Elliott to fruit during the first two seasons in the field significantly reduced cumulative yields over the first 4 years with the most pronounced effect occurring in 'Elliott'. The risk of infection by pollenborne viruses and the potential of poorer plant establishment resulting from excessive precocity both suggest that a method to eliminate, or at least inhibit, flowering in the nursery and during field establishment would be highly desirable.

Foliar applications of a plant growth regulator would provide a low-labor, low-cost method to suppress flowering. Foliar applications of commercially formulated gibberellin (GA₃) are now a common industry practice in tart cherry production to prevent precocious cropping in young trees and to maintain long-term fruitfulness by increasing vegetative growth in aging or diseased orchards (Nugent, 2006). This ability of post-bloom foliar applications of GA₃ to suppress or prevent flowering the next season was first observed in tart cherry (*Prunus cerasus* L.) in 1956 (Bukovac et al., 1986), and similar effects have been observed to varying degrees in other *Prunus* species, including almond (*P. amygdalus* Batsch.), apricot (*P. armeniaca* L.), peach [*P. persica* (L.) Batsch], sweet cherry (*P. avium* L.), and plum (*P. domestica* L.) (Bradley and Crane,

1960). Despite considerable research with other *Prunus* crops, implementation into commercial applications has not been as extensive as that for tart cherry (reviewed by Southwick and Glozer, 2000). Similarly, there are multiple reports on the use of foliar applications of GA₃, GA₄, GA₇, and combination GA₄₊₇ to suppress flower bud initiation in apple (*Malus ×domestica* Borkh.), but variability in response has inhibited commercialization (reviewed by Greene, 2000). Bloom and postbloom applications of GA₃ have also been shown to effectively reduce flower bud initiation in a number of other perennial species, including pear (*Pyrus communis* L.; Dennis et al., 1970), olive (*Olea europea* L.; Fernandez-Escobar et al., 1992), and mango (Kachru et al., 1971).

In highbush blueberry, Mainland and Eck (1969a) observed reduced return bloom from full-bloom applications of GA₃ to 'Coville' under greenhouse conditions, but did not see a similar reduction when applied to 'Coville' plants in the field (Mainland and Eck, 1969b). Retamales et al. (2000) tested foliar applications of GA₃ applied 7 to 13 weeks after full bloom on 'Bluecrop' and 'Elliott' and reported 20% to 40% reductions in flower bud numbers, but found the results in the field were extremely variable and as a result were not statistically significant. Several reports indicate that GA₄₊₇, and more specifically GA₇, is more effective than GA₃ for inhibiting flower bud initiation in apple (Bertelsen et al., 2002; Greene, 1993; McArtney and Li, 1998; Tromp, 1982; Wertheim, 1982). The purpose of this study was to determine if flower bud initiation in blueberry could be consistently suppressed with a commercial GA₄₊₇ formulation (ProVide; Valent BioSciences Corp., Libertyville, Ill.).

Materials and Methods

In Spring 2003, 1-year-old rooted cuttings of 'Bluecrop' highbush blueberry were obtained from a commercial nursery and established in 11-L pots at the Philip E. Marucci Center for Blueberry and Cranberry Research and Extension, Rutgers University, Chatsworth, N.J. Plants were potted in a 1 peat : 1 sand mixture and supplied with 14N–14P–14K Osmocote (Scotts Miracle-Gro, Marysville, Ohio) fertilizer at a rate of 30 mL per plant and watered with overhead irrigation for 1 h daily. Potted plants were selected for uniformity and assigned to one of 20 treatments and 10 replications (Table 1). Fifteen of the 20 treatments had a rate by application timing factorial treatment structure (3 rates × 5 timings). The three rates of GA₄₊₇ were high-volume foliar applications of 200, 400, and 600 mg·L⁻¹ a.i. applied with a low-pressure hand sprayer. Each application timing treatment was applied twice at 1-week intervals. Plants assigned to the earliest treatment received GA₄₊₇ applications on 2 July and 9 July with later timing treatments being 16 July and 23 July, 30 July and 6 Aug., 13 Aug. and 20 Aug., and

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Use of trade names does not imply an endorsement of the products named nor criticism of similar ones not named.

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Table 1. Plant growth regulator treatments applied to potted plants of Bluecrop highbush blueberry in 2003.^z

	GA ₄₊₇ rate (mg·L ⁻¹)	Timing	Application dates
1	Control, water sprays		
2	Control, no sprays		
3	200	1	2 July, 9 July
4	400	1	2 July, 9 July
5	600	1	2 July, 9 July
6	200	2	16 July, 23 July
7	400	2	16 July, 23 July
8	600	2	16 July, 23 July
9	200	3	30 July, 6 Aug.
10	400	3	30 July, 6 Aug.
11	600	3	30 July, 6 Aug.
12	200	4	13 Aug., 20 Aug.
13	400	4	13 Aug., 20 Aug.
14	600	4	13 Aug., 20 Aug.
15	200	5	27 Aug., 3 Sept.
16	400	5	27 Aug., 3 Sept.
17	600	5	27 Aug., 3 Sept.
18	200	Weekly	2 July to 3 Sept.
19	400	Weekly	2 July to 3 Sept.
20	600	Weekly	2 July to 3 Sept.

^zRate is the a.i. concentration of GA₄₊₇ (ProVide).

27 Aug. and 3 Sept. Additional treatments (not in the 3 × 5 factorial matrix) included 200, 400, and 600 mg·L⁻¹ a.i. applied weekly from 2 July to 3 Sept., a water-sprayed control, and an untreated control. To avoid rewetting treated leaves, plants were moved to a greenhouse before application and returned to the overhead-irrigated area 48 h after treatment application. Treatment effects were evaluated in Spring 2004 by counting floral and vegetative buds on each plant.

A second set of rooted cuttings of 'Bluecrop' was obtained in Spring 2004, potted, and grown as described previously. Plants were selected for uniformity and assigned to one of 10 treatments and 10 replications (Table 2). GA₄₊₇ was applied at 400 mg·L⁻¹ in three weekly applications at three different timings. Plants assigned to the earliest timing were treated on 7 July, 14 July, and 21 July. The second timing was applied on 28 July, 4 Aug., and 11 Aug., and the latest timing was applied on 18 Aug., 25 Aug., and 1 Sept. One treatment received three GA₄₊₇ applications at 4-week intervals, on 7 July, 4 Aug., and 1 Sept. Four of the GA₄₊₇ treatments included weekly applications from 7 July to 1 Sept. at a.i. concentrations of 50, 100, 200, and 400 mg·L⁻¹. The 2004–2005 study also included untreated and water-sprayed con-

trols. Treatment effects were evaluated in the late winter and spring of 2005 by counting flower and vegetative buds, and by measuring stem and internode length.

In Spring 2005, a third set of rooted cuttings consisting of 'Bluecrop' and 'Duke' were obtained and established as described previously. Plants were assigned to one of 12 treatments and 10 replications (Table 3). The cultivars Duke and Bluecrop were both assigned to three GA₄₊₇ application timings and untreated control treatments. Each timing treatment consisted of three repeat applications of 400 mg·L⁻¹ of GA₄₊₇ with the earliest timing treated on 4 Aug., 11 Aug., and 18 Aug.; the intermediate timing treated on 18 Aug., 25 Aug., and 1 Sept.; and the latest timing treated on 1 Sept., 8 Sept., and 15 Sept. To compare different GA formulations, additional treatments consisted of GA₄, GA₇, GA₄₊₇, or GA₃ (ProGibb; Valent BioSciences Corp.) applied to 'Bluecrop' at the intermediate timing and at a.i. concentrations of 200 mg·L⁻¹.

Bud count data were analyzed using the Proc GLM routine of SAS version 9.1 (SAS Institute, Cary, N.C.). Percent data were subjected to logit transformation before analysis. Where treatments were continuous such as rate response and timing response, trends were analyzed using orthogonal contrasts. When significant interactions were found, treatment means separation was performed using the PDIFF option of the LSMEANS statement.

Results

2003–2004 study. Of the GA treatments applied in 2003, all showed significant reduction in flower bud numbers compared with the controls. The most dramatic reduction in flower bud numbers was in the plants that received weekly applications of GA₄₊₇ throughout the summer. In these plants, flower bud numbers were less than one per plant (Table 4). However, these continuous treatments also showed stunted growth with 27% to 39% reductions in vegetative bud numbers (Table 5) and reduced stem height (data not shown).

Among the factorial treatments, flower bud number was inversely correlated with GA₄₊₇ rate to 400 mg·L⁻¹ but showed no difference in response between 400 and 600 mg·L⁻¹. Among timing treatments, the

greatest degree of suppression resulted from the mid-July treatments (timing 2) and late August to early September treatments (timing 5) as indicated by the significant quadratic trend (Table 4). Differences in vegetative bud numbers among the factorial treatments were numerically small but statistically significant, showing a significant rate × timing interaction ($P = 0.010$). This significant interaction was the result of a lack of response at the 200 mg·L⁻¹ rate but increasing vegetative bud numbers with later applications at the higher GA₄₊₇ rates (data not shown).

2004–2005 study. Based on results from the first study, a series of treatments was designed to determine whether a greater response could be obtained by applying the material in three weekly applications instead of two. Alternatively, if applications throughout the season were required to suppress flowering, could these be made at monthly intervals or at weekly intervals at lower rates to reduce negative effects on plant growth? For continuous weekly applications throughout the summer, there was a dose-dependent reduction in flower bud number, in which the highest rate had 33% as many flower buds as the water-sprayed control (Fig. 1). Although the highest rate had significantly fewer vegetative bud numbers, this treatment also produced significant increases in internode length, resulting in no significant difference in plant height between the highest and lowest rate treatments (data not shown).

Among treatments receiving three GA₄₊₇ applications, the latest application had the greatest degree of flower bud suppression with 4.6 flowers per plant compared with 36.4 for the water-sprayed control (Fig. 1). Vegetative bud numbers were not significantly affected by this treatment. The reduction in total buds (vegetative + floral) was offset by a 20% increase in internode length, resulting in no significant effect in plant height (data not shown). The next most effective of these treatments was the monthly application treatment, which also included a September application (Fig. 1).

2005–2006 study. Based on results from the 2004–2005 study, an experiment was initiated in 2005 to compare additional late-season applications as well as to examine differences in response between two cultivars, Bluecrop and Duke. The early treatments in this study were in early August, and the late treatment applications were in early to mid-September (Table 3). Some of the plants in this study were damaged by late-winter deer browsing. Those plants with obvious deer damage were excluded from the analysis, resulting in fewer than 10 replications per treatment. None of the 2005 treatments differed significantly in vegetative bud numbers or in plant height. Among GA₄₊₇ treatments, the latest application again had the lowest flower bud numbers (Fig. 2A). In the untreated controls, 'Duke' had higher flower bud numbers but similar vegetative bud numbers as 'Bluecrop' indicating a

Table 2. Growth regulator treatments applied in 2004 to Bluecrop highbush blueberry.^z

	Treatment description	Rate (mg·L ⁻¹)	Dates
1	Water-sprayed control		
2	Untreated control		
3	GA ₄₊₇ , early timing	400	7 July, 14 July, 21 July
4	GA ₄₊₇ , midtiming	400	28 July, 4 Aug., 11 Aug.
5	GA ₄₊₇ , late timing	400	18 Aug., 25 Aug., 1 Sept.
6	GA ₄₊₇ , weekly	50	7 July–1 Sept.
7	GA ₄₊₇ , weekly	100	7 July–1 Sept.
8	GA ₄₊₇ , weekly	200	7 July–1 Sept.
9	GA ₄₊₇ , weekly	400	7 July–1 Sept.
10	GA ₄₊₇ , monthly	400	7 July, 4 Aug., 1 Sept.

^zRate is the a.i. concentration of GA₄₊₇ (ProVide).

Table 3. Plant growth regulator treatments applied to Bluecrop and Duke highbush blueberry in 2005.^z

	Cultivar	Treatment	Rate (mg·L ⁻¹)	Timing	
				First app	Last app
1	Bluecrop	Control			
2	Duke	Control			
3	Bluecrop	GA ₄₊₇	400	4 Aug.	18 Aug.
4	Bluecrop	GA ₄₊₇	400	18 Aug.	1 Sept.
5	Bluecrop	GA ₄₊₇	400	1 Sept.	15 Sept.
6	Duke	GA ₄₊₇	400	4 Aug.	18 Aug.
7	Duke	GA ₄₊₇	400	18 Aug.	1 Sept.
8	Duke	GA ₄₊₇	400	1 Sept.	15 Sept.
9	Bluecrop	GA ₄₊₇	200	18 Aug.	1 Sept.
10	Bluecrop	GA ₄	200	18 Aug.	1 Sept.
11	Bluecrop	GA ₇	200	18 Aug.	1 Sept.
12	Bluecrop	GA ₃	200	18 Aug.	1 Sept.

^zThe GA₄₊₇ used was the commercial formulation ProVide. The GA₃ was the commercial formulation ProGibb. Each timing treatment represented three weekly applications with the first and last application date shown.

Table 4. Flower bud counts collected in Spring 2004 for GA₄₊₇ treatments applied to Bluecrop highbush blueberry in Summer 2003.

Treatment	Rate (mg·L ⁻¹)			Main effect means
	200	400	600	
	(flower buds/plant)			
Weekly application	0.5	0.2	0.2	
2 July, 9 July	11.0	8.3	9.1	9.5
16 July, 23 July	7.1	6.7	4.0	5.9
30 July, 6 Aug.	12.1	4.3	6.0	7.5
13 Aug., 20 Aug.	10.7	7.4	8.0	8.7
27 Aug., 3 Sept.	8.7	6.3	5.2	6.7
Main effect means	9.9	6.6	6.5	
Untreated control		21.6		
Water-sprayed control		19.3		
Factorial treatment analysis (3–17)				
Rate		<0.001		
Timing		0.036		
Rate × timing		0.487		
Trend analysis				
Rate – linear		<0.001		
Rate – quadratic		0.059		
Timing – linear		0.333		
Timing – quadratic		0.391		
Timing – cubic		0.004		

Table 5. Vegetative bud counts collected in Spring 2004 for GA₄₊₇ treatments applied to Bluecrop highbush blueberry in Summer 2003.^z

Treatment	Rate (mg·L ⁻¹)		
	200	400	600
	(vegetative buds/plant)		
Weekly application	53.6	44.5	45.8
2 July, 9 July	72.9	55.2	75.0
16 July, 23 July	75.4	75.4	59.5
30 July, 6 Aug.	64.2	78.8	72.2
13 Aug., 20 Aug.	76.8	81.2	68.7
27 Aug., 3 Sept.	88.9	88.9	80.7
Untreated control		75.5	
Water-sprayed control		73.4	
Factorial analysis			
Rate		0.276	
Timing		<0.001	
Rate × timing		0.010	

^zUnits are the number of vegetative buds per plant.

higher degree of precocity consistent with the performance of these two cultivars in commercial fields. However, the latest GA₄₊₇ applications were more effective on ‘Duke’

than ‘Bluecrop’ indicating that flower bud suppression treatments were more effective on the more precocious variety. This higher degree of response is confirmed by analyzing the data for the first eight treatments as a cultivar by timing factorial treatment structure. In such an analysis, flower bud number showed significant cultivar-by-application-time interaction ($P = 0.011$). Where GA₄, GA₄₊₇, GA₇, and GA₃ were compared at similar rates and timing, the GA₃ appeared to be somewhat more effective than GA₄, GA₄₊₇, or GA₇ (Fig. 2B); however, none of these treatments was applied at optimal timing.

Discussion

Over three seasons, foliar applications of GA₄₊₇ significantly reduced flower bud number the next year. In each of these three studies, the degree of flower bud suppression from some treatments exceeded that reported by Retamales et al. (2000). The later applications, particularly those applied in September, were the most effective in suppressing

flowering. Work by Gough et al. (1978) suggested that meristematic changes associated with flower bud differentiation in ‘Bluecrop’ occurred at the fourth node from the terminal bud as early as late July and that bud differentiation was asynchronous, progressing acropetally. Based on these histologic data, Retamales et al. (2000) applied GA₃ from 7 to 13 weeks after full bloom (AFB) to correspond to the meristematic transition chronology proposed by Gough et al. (1978). Likewise, Retamales et al. (2000) attributed the inconsistent and incomplete response to the asynchronous nature suggested by the histologic evidence and suggested that repeat applications may be necessary for more consistent floral suppression. The more consistent and complete suppression reported here was more likely the result of a later application window than of a more active GA. Hall et al. (1963) reported that daylength extension could effectively prevent flower bud formation in ‘Coville’, ‘Earliblue’, and ‘Jersey’ highbush blueberry, and that the critical photoperiod ranged from 12 to 14 h of daylight, varying with cultivar. In a related study, Hall and Ludwig (1961) found similar results with multiple genotypes of lowbush blueberry (*V. angustifolium* Ait.). Their work did not include histologic comparisons of meristematic development, but was based on visual changes in bud morphology. A photoperiodic trigger for floral induction would explain why the September treatments, 15 to 17 weeks AFB and ≈2 to 4 weeks later than the latest treatments of Retamales et al. (2000), were more effective in suppressing flower bud formation. At the Chatsworth location, the time from sunrise to sunset on 1 Sept. is 13 h 4 min.

Additional work is needed to determine the critical period for flower bud suppression in additional commercially important cultivars. Once optimal timing has been determined, it may be possible to achieve sufficient suppression with a single foliar application. Further testing is also required to determine which of the GAs are most effective in flower bud suppression. Currently, commercial formulations of GA₃ are registered in the United States for full bloom applications to increase fruit set (ProGibb 4% and ProGibb plus 2X) by increasing parthenocarpy (Hooks and Kenworthy, 1971; Mainland and Eck, 1968, 1969a, 1969b; NeSmith, 2002; NeSmith and Krewer, 1999).

Among our experimental treatments, the highest degree of flower bud suppression without stunting plant growth was 95%. This suggests that GA treatments alone would be insufficient for eliminating the risk of infection with pollenborne viruses. This degree of suppression, however, would be sufficient to control precocity in new plantings and would dramatically reduce the amount of pruning and bud removal necessary to eliminate flowering in the nursery. Furthermore, using lower rates of GA to partially suppress flower bud formation may provide a method to manage crop

Fig. 1. The effect of growth regulator application in 2004 on floral and vegetative bud numbers of 'Bluecrop' highbush blueberry in the spring of 2005. GA₄₊₇ was applied in three applications at a rate of 400 mg·L⁻¹, at different timings (A, C), and compared with a water-sprayed control (WSC). The early timing was 7 July to 21 July; the middle timing was 28 July to 11 Aug., and the late timing was 18 Aug. to 1 Sept. Alternatively, treatments were made at weekly intervals from 7 July to 1 Sept. at four different a.i. concentrations (B, D). Vertical bars represent values for least significant difference.

Fig. 2. The effect of growth regulator application in 2005 on floral bud numbers of two highbush blueberry cultivars in the spring of 2006. GA₄₊₇ was applied in three applications to 'Bluecrop' and 'Duke' at a rate of 400 mg·L⁻¹ at different timings (A) and compared with an untreated control. Applications for the earliest timing were from 4 Aug. to 18 Aug., and the latest applications were from 1 Sept. to 15 Sept. (See Table 3 for a full listing of treatments.) Alternatively, different gibberellins were applied to 'Bluecrop' at 200 mg·L⁻¹ and compared with an untreated control (B). Bars labeled with the same letter are not significantly different at ($P = 0.05$) within cultivar.

load for maximizing fruit size and quality, similar to the thinning carried out for tree fruit crops.

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