Response of Rabbiteye Blueberry (*Vaccinium ashei* Reade) to the Growth Regulators CPPU and Gibberellic Acid

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Abstract. Experiments were conducted during 1999 and 2000 at Griffin, Ga., with rabbiteye blueberries (*Vaccinium ashei* Reade) to determine how the growth regulator CPPU affected fruit set, berry size, and yield. CPPU (applied at two different timings) was used alone, and in conjunction with GA₃ on mature, field-grown 'Tifblue' plants. A control treatment without either growth regulator was also included. The CPPU concentration used was 10 mg·L⁻¹ (a single application per treatment), and the GA₃ concentration used was 200 mg·L⁻¹ (two applications per treatment). Results from both years showed a positive benefit of CPPU with respect to fruit set and berry size, especially in the absence of GA₃. Depending on timing, berry number per plant was increased by more than 200% in 1999 using CPPU. Berry size increases of more than 30% occurred in 2000 when CPPU alone was applied at 17 d after flowering (DAF). CPPU did not increase berry size of GA₃-treated plants in either year. Total yield per plant during 2000 was 5.0, 7.1, and 8.3 kg for control, CPPU applied 7 DAF, and CPPU applied 17 DAF treatments, respectively, without GA₃. While CPPU did substantially increase fruit set, berry size, and yield of 'Tifblue', there was a notable delay in fruit ripening. These results suggest that CPPU may be useful for increasing yield of rabbiteye blueberries under conditions of inadequate fruit set (such as occurs in much of the Southeast), but a delay in ripening will likely result. Chemical names used: *N*-(2-chloro-4-pyridyl)-*N'*-phenylurea (CPPU); gibberellic acid (GA₃).

Rabbiteye blueberry production has been on the increase throughout the southeastern United States over the past few years (Moore, 1994; Scherm et al., 2002). Problems of poor fruit set of rabbiteye blueberries due to erratic or inadequate pollination, which can lead to substandard fruit yields, have been recognized for years (Lyrene and Crocker, 1983; Lyrene and Goldy, 1983). In a recent report (Scherm et al., 2002), over 65% of growers surveyed in Georgia declared poor fruit set as a major or moderate horticultural problem.

There has been considerable research efforts in Georgia over the past decade with the growth regulator gibberellic acid (GA₃) aimed at overcoming some of the fruit set problems with rabbiteye blueberry. NeSmith and Krewer (1992) disclosed that the degree of activity of GA₃ depends on the stage of flower bud development at the time of application. It was further demonstrated that GA₃ could be used to induce fruit set of freeze-damaged blueberries (NeSmith et al., 1995, 1999). Other information on response of rabbiteye blueberry to GA₃ has also recently been reported (NeSmith and Krewer, 1997a, 1997b, 1999). GA₃ has become widely used by growers, particularly in

the southeastern United States, to increase fruit set and yield of rabbiteye. In fact, a recent survey indicated that more than 50% of the acreage in Georgia received applications of GA₃ (Scherm et al., 2002).

Even though there have been positive benefits from using GA₃ in rabbiteye blueberries, there are problems with small, late-ripening fruit when using this growth regulator (NeSmith and Krewer, 1999; Williamson et al., 1995). The cytokinin compound CPPU has shown some positive results in increasing fruit size and/or set of several crops, including table grapes (*Vitis* sp.), kiwi fruit (*Actinidia chinensis* Planch and *A. deliciosa*), apples [*Malus domestica* (Borkh.) Mansf.], pear (*Pyrus communis* L.), table olives (*Olea europaea* L.), and Japanese persimmon (*Diospyros khaki* Thunb.) (Antognozzi et al., 1993a, 1993b; Flaishman et al., 2001; Greene, 1989, 1993; Looney, 1993; Nickell, 1985, 1986; Reynolds et al., 1992; Sugiyama and Yamaki, 1995). The objective of this research was to examine possible enhancement of berry size, fruit set, and yield of rabbiteye blueberries using the growth regulator CPPU with and without GA₃.

Materials and Methods

Mature (6 years old in 1999) field-grown 'Tifblue' blueberry plants in Griffin, Ga., were used for this experiment. A split-plot experiment was conducted in Spring 1999 and 2000, with main plots of two levels of GA₃ (+ and - GA₃), and subplots of three CPPU treatments (no CPPU, CPPU timing 1, and CPPU timing 2). When 50% or more of flowers were at stage 5 to 6 of development (Spiers, 1978), applica-

tions of the growth regulator ProGibb (4% GA₃) were made to whole plants. The timing and rate of GA₃ were based on previous work (NeSmith and Krewer, 1992, 1997a, 1997b). GA₃ treatments consisted of one application of 200 mg·L⁻¹ at the appropriate growth stage, followed by a second application (same concentration) 14 d later. These were applied to five rows (every other row out of 10 total rows) containing 10 plants in each row. The remaining five rows were not treated with GA₃. CPPU applications were applied to single plant plots in each of the GA₃ and non-GA₃ rows. The treatments were: 1) no CPPU, 2) CPPU applied 1 d after the last GA₃ application (≈7 d after flowering), and 3) CPPU applied 10 d after the last GA₃ application (≈17 d after flowering). All CPPU applications were applied at a concentration of 10 mg·L⁻¹. All growth regulator applications consisted of spraying whole plants to the point of drip using a back pack sprayer. All sprays utilized the nonionic surfactant X-77 at 0.25%. There were five replications (single plant) of each GA₃ and CPPU combination. Treated plants were bordered by one plant on each side in the row.

Data collection from all treatments in 1999 consisted of fruit number per plant and average fruit weight. Berry weight was determined two times on a 25-berry sample of ripe fruit from each treatment and each replication. One complete harvest was made for all bushes on 6 July in 1999; however, bird problems prevented continuous harvesting of fruit, so yield estimations were made. Fruit number per plant was determined by harvesting and counting all ripe and green fruit on plants. Yield estimations were made by multiplying fruit number per plant by average berry weight.

In 2000, treatment plants were protected from birds by utilizing commercial bird netting. The netting was put in place just before fruit began to ripen. Data collection during 2000 was the same as in 1999 except for the following additions. In 2000, fruit set of all plants was determined by tagging three shoots per plant and counting the number of flowers per shoot and later counting the number of fruit. Yield was determined for each treatment by hand-harvesting all ripe fruit on four dates in 2000 (29 June, 14 July, 2 Aug., and 17 Aug.). At each harvest, average berry weight was determined on a 100-berry sample of ripe fruit. All data were subjected to analysis of variance procedures (SAS Institute, 1990).

Results and Discussion

In 1999, berry number per plant was substantially increased for plants treated with CPPU at either timing, while no significant difference was apparent due to GA₃ application (Table 1). Likewise, in 2000, fruit set generally increased with applications of both CPPU alone, and CPPU applied in conjunction with GA₃ (Table 2). Fruit set overall during 2000 was much greater than in 1999 for all treatments. During 2000, there was a trend (although not significant) for GA₃ to increase fruit set compared to pollination alone, which is similar to earlier reports using the growth

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regulator (NeSmith and Krewer, 1992 and 1997b). However, the use of CPPU caused increases in fruit set of both nontreated and GA₃-treated plants. CPPU has been shown to increase fruit set in watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nak.], muskmelon (*Cucumis melo* L.), Chinese gourd (*Lagenaria leucantha*), and Japanese persimmon (Hayata et al., 1995; Hayata et al., 2000; Sugiyama and Yamaki, 1995; Yu et al., 2001). However, in apple, CPPU has been shown to reduce crop load (Greene, 1989), and in grapes CPPU had no effect on berry set (Reynolds et al., 1992; Zabadal and Bukovac, 2000).

Average berry weights at the first harvest during 1999 and 2000 (Table 3) showed a tendency for GA₃-treated berries, overall, to be slightly smaller than non-GA₃-treated berries, which agrees with previous reports (NeSmith et al., 1995; NeSmith and Krewer, 1999). In the absence of GA₃, average berry weight of CPPU-treated plants was greater than that of plants receiving no CPPU. CPPU applied 17 d after flowering tended to result in the greatest increase in berry weight as compared to no CPPU. CPPU had much less effect on berry weight when applied in conjunction with GA₃. Effects of CPPU and GA₃ on berry weight were found across all harvests during 2000 (Table 4). CPPU increased average berry weight by 15% to 34% across all harvests when compared to pollination alone.

Research with other crops has shown one of the principle benefits of CPPU is increased fruit size. Grapes have been increased in size by as much as 35% with CPPU depending on timing and rate (Nickell, 1985, 1986; Reynolds et al., 1992; Zabadal and Bukovac, 2000). In kiwifruit, CPPU applied 14 d after bloom increased fruit size by more than 25% (Antognozzi et al., 1993b). Fruit size of apple has been increased by 15% to 20% using CPPU, but some resulting misshapened fruit was reported (Curry and Greene, 1993; Greene, 1989, 1993; Sugiyama et al., 1993; Tartarini et al., 1993). Fruit size of other crops, including olive and pear, has been increased with CPPU also (Antognozzi et al., 1983a; Flaishman et al., 2001), while still other crops (watermelon, muskmelon, and Japanese persimmon) have shown no response of fruit size to CPPU (Hayata et al., 1995, 2000; Sugiyama and Yamaki, 1995).

Early work with apples (Greene, 1989) indicated that CPPU thinned crop load, supporting the possibility that the thinning effect was the reason for fruit size increase. However, subsequent research with pear (Flaishman et al., 2001) concluded that there was a direct effect of CPPU on sizing, not just a thinning effect. In the current experiment with blueberries, fruit thinning was not responsible for sizing of CPPU fruit, as many of the treatments with the greater degree of fruit set were those with the larger berry weight. Other investigations have revealed that CPPU can induce increased cell division and expansion, which leads to increased fruit size (Lewis et al., 1996; Looney, 1993; Yu et al., 2001).

Total yield per plant for 1999 and 2000 indicate no yield differences in response to

Table 1. Total number of berries per bush for the growing season for GA₃- and CPPU-treated 'Tifblue' blueberries in Griffin, Ga., during 1999.

CPPU treatment	Total berry no. per bush for season		
	With GA ₃	Without GA ₃	Avg
No CPPU	435 a A ^z	553 a A	494 a
CPPU Timing 1	1261 b A	988 ab A	1124 b
CPPU Timing 2	1680 b A	1422 b A	1551 b
Average	1125 A	988 A	

^zValues in a column followed by the same lower case letter were not significantly different at $P \leq 0.05$; values in a row followed by the same capital letter were not significantly different at $P \leq 0.05$.

Table 2. Percent fruit set for GA₃- and CPPU-treated 'Tifblue' blueberries in Griffin, Ga., during 2000.

CPPU treatment	Fruit set percentage		
	With GA ₃	Without GA ₃	Avg
No CPPU	82% a A ^z	68% a A	75% a
CPPU Timing 1	85% ab A	77% ab A	81% ab
CPPU Timing 2	98% b A	93% b A	96% b
Average	88% A	79% A	

^zValues in a column followed by the same lowercase letter were not significantly different at $P \leq 0.05$; values in a row followed by the same capital letter were not significantly different at $P \leq 0.05$.

Table 3. Average individual ripe berry weight at the first harvest (6 July 1999 and 29 June 2000) for GA₃- and CPPU-treated 'Tifblue' blueberries in Griffin, Ga., during 1999 and 2000.

CPPU treatment	Avg ripe berry wt (g)		
	With GA ₃	Without GA ₃	Avg
1999			
No CPPU	1.04 a A ^z	1.18 a B	1.11 a
CPPU Timing 1	1.16 a A	1.26 ab A	1.21 ab
CPPU Timing 2	1.16 a A	1.34 b B	1.25 b
Average	1.12 A	1.26 B	
2000			
No CPPU	1.11 a A	0.99 a A	1.05 a
CPPU Timing 1	0.98 b A	1.16 b B	1.07 a
CPPU Timing 2	1.13 a A	1.33 c B	1.23 b
Average	1.07 A	1.16 A	

^zValues in a column for a year followed by the same lowercase letter were not significantly different at $P \leq 0.05$; values in a row for a year followed by the same capital letter were not significantly different at $P \leq 0.05$.

Table 4. Average individual ripe berry weight over all four harvests for GA₃- and CPPU-treated 'Tifblue' blueberries in Griffin, Ga., during 2000.

CPPU treatment	Avg ripe berry wt (g)		
	With GA ₃	Without GA ₃	Avg
No CPPU	1.02 ab A ^z	0.94 a A	0.98 a
CPPU Timing 1	0.97 a A	1.08 b A	1.03 a
CPPU Timing 2	1.11 b A	1.26 c B	1.19 b
Average	1.03 A	1.09 A	

^zValues in a column followed by the same lowercase letter were not significantly different at $P \leq 0.05$; values in a row followed by the same capital letter were not significantly different at $P \leq 0.05$.

GA₃ overall; however, there was an increase in yield in response to CPPU application (Table 5). Yields were more than 200% greater for CPPU-treated plants in 1999 than for plants receiving no CPPU, although 1999 yields overall were much less than during 2000. In 2000, there were no yield differences between CPPU treatments with GA₃; however, in the absence of GA₃, CPPU increased yields by as much as 66%. In both years, the yield increases were due to both increased berry numbers per plant and to increased berry size in response to CPPU. Total yield increases have been reported for CPPU used on other crops comparable to the yield increases observed for blueberry (Antognozzi et al., 1993b; Flaishman et

al., 2001). Yield increase from GA₃ alone did not occur in 1999, although yields for the GA₃ alone treatment in 2000 were 36% greater than for the pollinated control. Yield increases from GA₃ under field conditions have been previously reported, and as in the current experiment, results have been variable (NeSmith and Krewer, 1997a; Williamson et al., 1995).

Both growth regulators tended to cause delays in maturity, as is apparent from the percent of the fruit obtained at the first harvest each year (Table 6). Delays in ripening of blueberries from GA₃ have been documented previously, and tend to come from the lack of "seed" in fruit rather than from increased fruit loads (NeSmith and Krewer, 1999; Williamson

Table 5. Total yield per plant for GA₃- and CPPU-treated 'Tifblue' blueberries in Griffin, Ga., during 1999 and 2000.

CPPU treatment	Total yield (kg/bush)		
	With GA ₃	Without GA ₃	Avg
<i>1999</i>			
No CPPU	0.5 a A ^z	0.7 a A	0.6 a
CPPU Timing 1	1.5 b A	1.3 b A	1.4 ab
CPPU Timing 2	2.0 b A	1.9 b A	1.9 b
Average	1.3 A	1.3 A	
<i>2000</i>			
No CPPU	6.8 a A	5.0 a A	5.9 a
CPPU Timing 1	5.5 a A	7.1 ab A	6.3 a
CPPU Timing 2	6.5 a A	8.3 b A	7.4 a
Average	6.3 A	6.8 A	

^zValues in a column for a year followed by the same lowercase letter were not significantly different at $P \leq 0.05$; values in a row for a year followed by the same capital letter were not significantly different at $P \leq 0.05$.

^yYields for 1999 are estimates made from numbers of berries per plant and average fruit weight from two sampling dates. Yields for 2000 are actual harvests from four dates over the season.

Table 6. Percent of total fruit gathered at the first harvest for GA₃- and CPPU-treated 'Tifblue' blueberries each year in Griffin, Ga.

CPPU treatment	Percent fruit harvested at first harvest		
	With GA ₃	Without GA ₃	Avg
<i>1999</i>			
No CPPU	37% a A ^z	62% a A	50% a
CPPU Timing 1	18% b A	37% b B	28% b
CPPU Timing 2	4% b A	18% c A	11% c
Average	20% A	39% B	
<i>2000</i>			
No CPPU	15% a A	22% a A	19% a
CPPU Timing 1	4% ab A	13% ab A	9% ab
CPPU Timing 2	1% b A	4% b A	3% b
Average	7% A	13% A	

^zValues in a column for a year followed by the same lowercase letter were not significantly different at $P \leq 0.05$; values in a row for a year followed by the same capital letter were not significantly different at $P \leq 0.05$.

et al., 1995). In the current experiment, the naturally pollinated treatment ripened the fastest, with 62% and 22% of its crop ripe at the first harvest during 1999 and 2000, respectively. The later application of CPPU (timing 2) had the greatest delay in ripening. Less than 5% of this treatment's fruit were ripe during the first harvest. Others have reported that CPPU tended to delay maturity in apple (Greene, 1989), grape (Reynolds et al., 1992), and Japanese persimmon (Sugiyama et al., 1993).

In summary, this research suggests that CPPU usage can enhance yield of 'Tifblue' rabbiteye blueberries under field conditions, even in the absence of GA₃. The yield increase results from both increased fruit set and berry size. The use of GA₃ has been beneficial in rabbiteye blueberry production in the Southeast, especially for freeze rescue (NeSmith et al., 1995, 1999). However, fresh fruit varieties often do not benefit from GA₃ due to the resulting reduced berry size and delayed ripening. The data here strongly suggest that CPPU may overcome the small berry size problem to a degree, but delays in maturity will likely occur. Berry size and maturity date are less important for processed blueberries; but again, CPPU would likely be useful to increase overall yields of those processed varieties. These findings should encourage further exploration of using CPPU in blueberry

production. Experiments to better define rates and timing of the growth regulator are needed, and tests of cultivar and species responses (i.e., rabbiteye vs. southern highbush) need to be conducted as well.

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