Ethephon and Methyl Jasmonate Affect Fruit Detachment in Rabbiteye and Southern Highbush Blueberry

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Abstract. Two abscission agents, ethephon and methyl jasmonate, were investigated in five studies to determine their potential for increasing fruit detachment during harvest in rabbiteye (*Vaccinium ashei* Reade) and southern highbush (hybrids based largely on *Vaccinium corymbosum* L. and *Vaccinium darrowi* Camp.) blueberry. In the first study with a rabbiteye blueberry genotype, T-451, ethephon applications up to 1000 mg·L⁻¹ did not affect fruit drop but reduced fruit detachment force (FDF) by up to 21%. In the second study with two southern highbush blueberry genotypes, ethephon (up to 1500 mg·L⁻¹) and methyl jasmonate (MeJa; up to 10 mM) applications resulted in significant fruit drop in ‘Star’ but neither of the growth regulators affected the fruit detachment characteristics of ‘Farthing’. In a third study with rabbiteye blueberry genotypes, MeJa applications of 10, 20, and 30 mM displayed an increasing linear trend in fruit drop in ‘Climax’ and linear and quadratic trends in fruit drop in ‘Powderblue’. In a fourth study with ‘Powderblue’, MeJa (20 mM) and ethephon (1000 mg·L⁻¹) applications resulted in rapid and significant fruit drop. The fruit drop induced by MeJa in this study was attenuated by the coapplication of aminoethoxyvinylglycine (AVG), an ethylene biosynthesis inhibitor, suggesting that MeJa induced fruit detachment partly through its effects on ethylene biosynthesis. In another study with the southern highbush blueberry genotype, O’Neal, MeJa applications (20 mM) induced significant fruit drop but ethephon (1000 mg·L⁻¹) applications did not affect fruit detachment. Overall, MeJa applications (20 mM or greater) generally induced rapid and extensive fruit abscission, often within 1 day after treatment. Applications of MeJa resulted in leaf yellowing and necrosis of leaf tips and margins, especially at high rates of application (20 mM or greater). Ethephon applications resulted in the abscission of mature and immature berries. Both ethephon and MeJa applications resulted in the detachment of the pedicel along with the fruit. Together, these data suggest that although ethephon and MeJa have the potential to be used as harvest aids in blueberry, the rates of application require further optimization to minimize potential phytotoxicity. Additionally, effective de-stemming of the berries may be essential if these compounds are to be used as harvest aids.

Blueberry (*Vaccinium* spp.) is rapidly emerging as a major fruit crop in the United States with over 72,000 acres under cultivation and a crop valued at over \$780 million U.S. in 2011 [U.S. Department of Agriculture (USDA), 2012]. Harvesting is a labor-intensive and expensive part of blueberry production. To decrease the costs associated with manual harvesting and to address issues with decreasing labor availability, there has been a renewed interest in exploring the use of mechanical harvesting. Mechanical harvesting

is often associated with significant losses such as ground loss (≈20%), mechanical injury to the berries and the plant, removal of immature fruit, and decline in the post-harvest quality of the fruit (Takeda et al., 2008; van Dalfsen and Gaye, 1999). The application of fruit-loosening agents that can decrease the force required for fruit detachment can contribute greatly toward enhancing the efficiency of mechanical harvesting (Burns, 2002; Burns et al., 2005).

Abscission agents have been used in different fruit crops to decrease the FDF and to enhance the efficiency of mechanical harvesting. Ethephon (2-chloroethylphosphonic acid), an ethylene-releasing agent, has been extensively evaluated as a potential fruit-loosening agent in a wide range of fruit such as citrus (*Citrus sinensis* L.), grape (*Vitis vinifera* L.), olive (*Olea europaea* L.), and cherry (*Prunus avium* L.) (Bukovac, 1979; Burns, 2002; Burns et al., 2008; Fidelibus et al., 2007; Yuan and Burns, 2004). In blueberry, ethephon has been evaluated previously in relation to its effects on concentrating fruit

ripening and also as a potential mechanical harvest aid (Ban et al., 2007; Dekazos, 1976, 1978; Eck, 1970; Howell et al., 1976). Ethephon applications reduced the fruit removal force and allowed for a reduction in the mechanical harvester vibration frequency required for fruit removal (Howell et al., 1976). The effects of ethephon on fruit abscission in rabbiteye and southern highbush blueberry have not been extensively evaluated, although the application of ethephon at 500 mg·L⁻¹ was reported to result in some fruit drop in the rabbiteye blueberry cultivar, Tifblue (Dekazos, 1978). Also, the application of ethephon at 200 mg·L⁻¹ was reported to have resulted in ≈33% fruit abscission by 7 d after treatment in ‘Tifblue’ (Ban et al., 2007).

Jasmonates are a group of compounds that include MeJa and its precursor, jasmonic acid, and are derived from the oxylipin pathway in plants. Jasmonates have diverse roles in plant growth and development and in plant responses to biotic and abiotic stress (Wasternack, 2007). Methyl jasmonate has been evaluated as a potential abscission agent in several fruit crops (Burns et al., 2008; Fidelibus et al., 2007; Gonzalez-Herranz et al., 2009; Hartmond et al., 2000; Kender et al., 2001). The application of MeJa, alone and in combination with other abscission agents, resulted in fruit abscission in sweet orange (Hartmond et al., 2000; Kender et al., 2001). Methyl jasmonate was also effective in reducing FDF and inducing fruit abscission in grapes (Fidelibus et al., 2007; Gonzalez-Herranz et al., 2009). Additionally, coronatine, a naturally produced compound with functional properties similar to the jasmonates, induced fruit abscission in citrus (Burns et al., 2003). The effects of MeJa on fruit detachment in blueberry have not been reported previously.

The main objective of this research was to determine the potential of ethephon and MeJa to induce fruit detachment in rabbiteye and southern highbush blueberry. To address this objective, the effects of different concentrations of ethephon and MeJa on fruit abscission and FDF were evaluated in multiple blueberry genotypes.

Materials and Methods

Expt. 1. Mature, four-year-old plants of T-451, a rabbiteye blueberry selection from the blueberry breeding program at the University of Georgia, were used in this experiment in 2008. The plants were grown at the Georgia Station in Griffin, GA. The experimental design was completely randomized with four replicates (one plant per replicate). Ethephon (Bayer CropScience, Kansas City, MO) was applied at 0, 100, 250, 500, 750, and 1000 mg·L⁻¹ along with 0.05% of a surfactant, Tween 20 (polyethylene glycol sorbitan monolaurate; Fisher Scientific, Pittsburgh, PA). Whole plants were sprayed until runoff using a hand pump sprayer. Approximately 50% to 75% of the fruit on the plants was mature (blue/black) at the time of application.

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All spray applications were performed at ≈ 1200 HR. The average daily temperature on the day of application was 24°C and ranged from 22 to 27°C during the experiment. One branch on each plant was tagged and the number of fruit on it was counted before the application of the treatments and at 7 d after treatment. The decrease in fruit number at 7 d after treatment in relation to the initial fruit number at 0 d was used to determine the percent fruit drop. FDF was measured using a pull force gauge (Force One FDIX; Wagner Instruments, Greenwich, CT). The gauge was fitted with an adapter designed at the Instrument Design and Fabrication Shop, University of Georgia. To measure the FDF, berries were detached from the plant along with the pedicel. The berries were placed within the adapter fitted to the gauge and the pedicel was pulled using a pair of pliers. The force (KgF) required for the detachment of the pedicel from the berry was recorded. At least 10 berries from each plant were used to determine the FDF at 0 and 7 d after treatment. The percent decrease in FDF at 7 d after treatment, in relation to the FDF at 0 d after treatment, is reported here.

Expt. 2. In 2009, abscission agent treatments were performed on two southern highbush blueberry cultivars, Star and Farthing, at a commercial blueberry farm in Waldo, FL (planting date: ca. 2004). The experimental design was a randomized complete block design with four replicates (one plant per replicate). These plants had been previously harvested once, either by hand or mechanically. Approximately 25% of the fruit on the plants were mature at the time of the treatment. Nine treatments were applied to each of the cultivars. All treatments involved the application of 0.15% of the adjuvant (Latron B-1956; Rohm and Haas, Philadelphia, PA). The control plants were treated with the adjuvant only. Ethephon was applied at 250, 500, 1000, and 1500 $\text{mg}\cdot\text{L}^{-1}$, whereas MeJa (Sigma-Aldrich, St. Louis, MO) was applied at 1, 2, 5, and 10 mM concentrations. All applications were performed using a backpack sprayer until runoff. The applications were performed at ≈ 1730 HR and the temperature at the time of application was $\approx 30^{\circ}\text{C}$. Bird netting was placed over the plants after the spray applications. Two branches were tagged on each plant and the number of fruit on the branches was counted at 0 and 5 d after treatment to calculate the percent fruit drop as described previously. The FDF was determined at 0 and 5 d after treatment using 10 mature fruit per plant, as described previously.

Expt. 3. In 2009, the effects of different concentrations of MeJa on fruit detachment in rabbiteye blueberry were evaluated separately on 'Climax' and 'Powderblue'. Mature four-year-old plants of 'Climax' and 'Powderblue' grown at the University of Georgia Horticulture Farm, Watkinsville, GA, were used in this study. The experimental design was completely randomized with four replicates (one plant per replicate) in both of these studies. Three different rates of application of MeJa, 10, 20, and 30 mM, with 0.15% of

the adjuvant (Latron B-1956), were applied in this study. The control was treated only with the adjuvant. All applications were made using a hand pump sprayer until runoff. Applications on 'Climax' were performed at 1430 HR. The average daily temperature on the day of the application was 28°C and ranged from 24 to 28°C during the duration of the experiment. Approximately 75% of the berries on the plant were mature at the time of application. One branch per plant was tagged and the fruit number on it was counted at 0, 3, and 7 d after treatment. The applications on 'Powderblue' were made at 1200 HR and the average daily temperature on the day of application was 24°C and ranged from 24 to 27°C during the duration of the experiment. Approximately 65% of the berries were mature at the time of application. One branch per plant was tagged and the fruit number on the branch was counted at 0 and 3 d after treatment.

Expt. 4. Mature six-year-old 'Powderblue' plants grown at the University of Georgia Horticulture Farm in Watkinsville, GA, were used to study the effects of growth regulator applications in 2011. The experimental design was completely randomized with six treatments and four replicates (one plant per replicate). The treatments were: control, MeJa (20 mM), ethephon (1000 $\text{mg}\cdot\text{L}^{-1}$), AVG (at 150 $\text{mg}\cdot\text{L}^{-1}$; Valent Biosciences, Walnut Creek, CA), MeJa (20 mM) with AVG (150 $\text{mg}\cdot\text{L}^{-1}$), and ethephon (1000 $\text{mg}\cdot\text{L}^{-1}$) with AVG (150 $\text{mg}\cdot\text{L}^{-1}$). All treatments included 0.15% of the adjuvant (Latron B-1956) and were performed using a hand pump sprayer until runoff. All applications were performed at ≈ 0900 HR. The average daily temperature on the day of application was 26°C and ranged from 26 to 29°C during the experiment. One branch on each plant was tagged before the applications and the immature (green or pink) fruit on this branch were removed to study the effects of the growth regulators, specifically on mature fruit. The mature fruit number on the tagged branches was counted at 0, 1, 2, and 3 d after treatment.

Expt. 5. The effects of MeJa (20 mM) and ethephon (1000 $\text{mg}\cdot\text{L}^{-1}$) on the southern highbush blueberry cultivar, O'Neal, were evaluated in 2012. Mature four-year-old

plants at the University of Georgia Horticulture Farm in Watkinsville, GA, were used in this study. The experimental design was completely randomized with three replicates (one plant per replicate). All treatments including the control were made along with 0.15% of the adjuvant (Latron B-1956). Applications were made at 0815 HR. The average daily temperature on the day of the application was 24°C and ranged from 24 to 26°C during the experiment. The applications were made using a hand pump sprayer until runoff. One branch per plant was tagged before application. The immature fruit were removed from the tagged branch and the number of mature fruit on the branch was counted at 0, 1, and 2 d after treatment.

Statistical analysis. All statistical analyses were performed using analysis of variance (ANOVA; $\alpha = 0.05$) using SigmaPlot 11 (Systat Software, San Jose, CA) and SAS (SAS Institute, Cary, NC). Data were transformed using arcsine square root transformation or square root transformation where required to satisfy the normality or equal variance assumptions. If ANOVA indicated a significant difference among treatments ($P < 0.05$), mean separation was performed using Fisher's least significant difference ($\alpha = 0.05$) or trend comparisons were performed using polynomial contrasts ($\alpha = 0.05$).

Results

Ethephon applications up to 1000 $\text{mg}\cdot\text{L}^{-1}$ did not have a significant effect on the extent of fruit drop in T-451 at 7 d after treatment but affected the FDF (Expt. 1; Table 1). A quadratic trend of decrease in FDF was observed in response to the ethephon treatments. The decrease in FDF was greatest at the 750 $\text{mg}\cdot\text{L}^{-1}$ rate of application ($\approx 21\%$).

In Expt. 2, ethephon applications up to 1500 $\text{mg}\cdot\text{L}^{-1}$ resulted in significant linear and quadratic trends of increase in fruit drop by 5 d after treatment in 'Star' (Table 2). The applications of MeJa up to 10 mM resulted in a significant linear trend of increase in fruit drop in 'Star' by 5 d after treatment. None of the treatments had a significant effect on fruit drop in 'Farthing' (Table 2). FDF was not significantly affected by the ethephon or

Table 1. Effects of ethephon application on fruit detachment in the rabbiteye blueberry genotype, T-451.

Treatment	Fruit drop (%) ^{a,y}	Decrease in FDF (%) ^{a,z}
Control	6.73	5.23
Ethephon 100 $\text{mg}\cdot\text{L}^{-1}$	7.19	16.85
Ethephon 250 $\text{mg}\cdot\text{L}^{-1}$	10.22	16.15
Ethephon 500 $\text{mg}\cdot\text{L}^{-1}$	20.41	18.80
Ethephon 750 $\text{mg}\cdot\text{L}^{-1}$	11.43	20.71
Ethephon 1000 $\text{mg}\cdot\text{L}^{-1}$	25.55	13.08
P value	NS	0.04
Contrasts	NS	Q**

^aMean values of the percent fruit drop and percent decrease in fruit detachment force (FDF) at 7 d after treatment in relation to that at 0 d after treatment are presented ($n = 4$).

^yAnalysis of variance (ANOVA; $\alpha = 0.05$) was performed followed by trend comparisons using polynomial contrasts (linear, quadratic, cubic, quartic, and quintic). The P values of the ANOVA are indicated when significant. None of the trends were significant for fruit drop data and only the quadratic trend (Q) was significant at the 1% level (**) for the FDF data.

NS = nonsignificant.

MeJa treatments in either of the two cultivars (Table 2).

In Expt. 3 with 'Climax', MeJa applications resulted in an increasing linear trend in the extent of fruit drop at 3 and 7 d after treatment (Fig. 1), indicating that fruit drop increased with increasing rates of MeJa application. The applications of MeJa resulted in up to 58% fruit drop by 7 d after treatment. In 'Powderblue', the extent of fruit drop induced by MeJa applications displayed significant linear and quadratic trends at 3 d after treatment (Fig. 1). Up to 65% fruit drop was observed in response to MeJa (30 mM) application in 'Powderblue'. The majority of fruit detachment in response to MeJa application occurred at the point of attachment of the pedicel to the peduncle. The pedicel remained attached to the fruit in greater than 95% of the fruit that dropped as a result of MeJa application.

In Expt. 4, MeJa (20 mM) application resulted in significantly higher fruit drop than that in the control by 1 d after treatment, a pattern that continued until 3 d after treatment

(Fig. 2). Ethephon (1000 mg·L⁻¹) application also resulted in fruit drop that was similar to that induced by MeJa at 2 and 3 d after treatment. Ethephon-induced fruit drop was significantly higher than that in the control at 2 and 3 d after treatment. Coapplication of AVG (150 mg·L⁻¹) resulted in the partial attenuation of the effects of MeJa (20 mM) on fruit drop at 3 d after treatment. Although MeJa alone resulted in 74% fruit drop by 3 d after treatment, the combination of MeJa and AVG resulted in 47% fruit drop. AVG did not affect the induction of fruit drop by ethephon, suggesting that the extent of ethylene released on ethephon absorption was sufficient to trigger abscission responses. The large majority of fruit detachment in response to ethephon and MeJa application in this experiment occurred at the point of attachment of the pedicel to the peduncle, similar to the observations in Expt. 3.

In Expt. 5, MeJa application (20 mM) resulted in ≈20% and 50% fruit drop by 1 and 2 d after treatment in 'O'Neal' (Fig. 3), significantly higher than that in the control.

The extent of fruit drop induced by ethephon (1000 mg·L⁻¹) was not significantly different from that in the control at 1 or 2 d after treatment.

In these experiments, ethephon applications, where effective, also resulted in immature fruit drop and some leaf abscission. Applications of MeJa were often observed to result in leaf yellowing. Also, high rates of application of MeJa (20 mM or greater) resulted in necrosis of leaf tips and margins, leaf drop, and limited detachment of immature fruit.

Discussion

Ethephon applications up to 1500 mg·L⁻¹ and at 1000 mg·L⁻¹ were effective in inducing fruit drop in 'Star' and 'Powderblue', respectively. In fact, 'Powderblue' was highly responsive to ethephon (1000 mg·L⁻¹), because it was effective in inducing fruit detachment within 2 d after treatment and ultimately resulted in greater than 55% fruit abscission. Similar rates of ethephon application (between 500 and 2500 mg·L⁻¹) were previously reported to be effective in reducing FDF and enhancing mechanical harvesting efficiency in highbush blueberry (Howell et al., 1976). However, in T-451 and 'Farthing', ethephon applications did not have a significant effect on fruit drop. Also, ethephon applications at 1000 mg·L⁻¹ were ineffective in inducing fruit drop in 'O'Neal'. These data are in contrast with a previous study in 'Tifblue', which indicated significant fruit drop with low rates of ethephon application (200 mg·L⁻¹; Ban et al., 2007). Blueberry fruit detachment responses to ethephon application may be dependent on the genotype under consideration, explaining the lack of fruit detachment responses to ethephon application in T-451, 'Farthing', and 'O'Neal'. Hence, the effect of different rates of ethephon application on additional genotypes may need to be further analyzed to determine the optimum range of its application. Additional factors such as differences in management techniques and/or the environmental conditions during treatment may have contributed to differences in fruit detachment in response to ethephon across the experiments reported here. Focused studies are required to address the influence of these factors.

Methyl jasmonate applications (especially at 20 mM or greater) were highly and consistently effective in inducing fruit drop in rabbiteye and southern highbush blueberry. The applications of MeJa (20 mM) resulted in significant fruit drop within 1 d and greater than 50% fruit drop by 2 d after treatment, suggesting that MeJa results in the rapid induction of abscission signaling mechanisms in blueberry. Lower rates of application of MeJa (up to 10 mM) induced significant fruit drop in 'Star' but were not effective in 'Farthing'. These data suggest that, like with ethephon, the sensitivity to MeJa applications may also depend on the genotype under consideration. In citrus, MeJa

Table 2. Effect of ethephon and methyl jasmonate (MeJa) on fruit detachment characteristics of the southern highbush blueberry cultivars, Star and Farthing.

Treatment	Fruit drop (%) ^{a,y}		Decrease in FDF (%) ^{a,y}	
	Star	Farthing	Star	Farthing
Control	4.56	4.52	18.40	23.59
Ethephon (250 mg·L ⁻¹)	7.10	11.84	11.93	27.64
Ethephon (500 mg·L ⁻¹)	3.12	4.30	22.26	34.20
Ethephon (1000 mg·L ⁻¹)	4.76	11.31	17.36	29.64
Ethephon (1500 mg·L ⁻¹)	35.52	17.79	33.33	29.32
MeJa (1 mM)	12.09	12.42	23.65	29.36
MeJa (2 mM)	5.98	13.90	23.19	35.98
MeJa (5 mM)	13.10	26.27	19.24	24.05
MeJa (10 mM)	21.54	21.27	22.91	32.85
P value	0.006	NS	NS	NS
Contrasts	L _E ,** Q _E ,** L _M *	ND	ND	ND

^aMean values of the percent fruit drop and percent decrease in fruit detachment force (FDF) at 5 d after treatment in relation to initial values at 0 d after treatment, are presented (n = 4).

^yAnalysis of variance (ANOVA; α = 0.05) was performed followed by trend comparisons using polynomial contrasts (linear, quadratic, cubic, and quartic), if significant. The P values of the ANOVA are indicated when significant. Trend comparisons were performed separately for ethephon and MeJa for the fruit drop data in 'Star'. The linear (L_E) and quadratic (Q_E) trends were significant for ethephon at the 1% level of significance (**), whereas the linear trend L_M was significant for MeJa at the 5% level of significance (*).

NS = nonsignificant; ND = not determined.

Fig. 1. Effect of methyl jasmonate on fruit drop in rabbiteye blueberry. Methyl jasmonate was applied at 0 mM (control), 10 mM, 20 mM, and 30 mM concentrations with 0.15% of an adjuvant. Fruit drop was determined at 3 and 7 d and at 3 d after treatment in the cultivars, Climax and Powderblue, respectively. In 'Climax' and 'Powderblue', analysis of variance indicated significant difference between the treatments within each time after treatment ($P < 0.05$; $n = 4$). Trend comparisons were performed using linear (L), quadratic (Q), and cubic (C) contrasts. Asterisks indicate that the trends were significant at the 5% (*) or 1% (**) level. NS indicates that the trend was nonsignificant.

Fig. 2. Effect of growth regulators on fruit drop in rabbiteye blueberry. Methyl jasmonate (MeJa; 20 mM), ethephon (1000 mg·L⁻¹), aminoethoxyvinylglycine (AVG; 150 mg·L⁻¹), MeJa (20 mM) + AVG (150 mg·L⁻¹), and ethephon (1000 mg·L⁻¹) + AVG (150 mg·L⁻¹) were applied to mature 'Powderblue' plants along with 0.15% adjuvant. The control treatment involved the application of the adjuvant only. The extent of fruit drop was determined at 1, 2, and 3 d after treatment. Analysis of variance indicated a significant difference among the treatments at each time after treatment ($P < 0.05$; $n = 4$). Mean separation within each time after treatment was performed using Fisher's least significant difference ($\alpha = 0.05$). Similar letters above the bars indicate no significant difference between the treatments within a given time after treatment.

Fig. 3. Effect of methyl jasmonate (MeJa) and ethephon on fruit drop in the southern highbush blueberry cultivar, O'Neal. Methyl jasmonate (20 mM) and ethephon (1000 mg·L⁻¹) were applied along with 0.15% of the adjuvant, whereas the control was treated with the adjuvant only. The extent of fruit drop was determined at 1 and 2 d after treatment. Analysis of variance indicated a significant difference among the treatments within each time after treatment ($P < 0.05$; $n = 3$). Mean separation within each time after treatment was performed using Fisher's least significant difference ($\alpha = 0.05$). Similar letters above the bars indicate no significant difference between the treatments within each time after treatment.

applications were effective in reducing FDF and inducing fruit abscission at a concentration of 10 mM and higher (Hartmond et al., 2000; Kender et al., 2001). Also, in grapes, MeJa was effective in inducing fruit drop at a concentration of ≈ 10 to 20 mM (Fidelibus et al., 2007), although lower rates of application (between 2 and 10 mM) were subsequently found to be better suited for mechanical harvesting applications (Gonzalez-Herranz et al., 2009). In blueberry, it may be expected that the fruit drop responses reported here would be reproducible under conditions of mechanical harvesting. In fact, it may be likely that fruit loosening and detachment under mechanical harvesting may be achieved with

rates of MeJa application lower than 20 mM. Hence, further research is required to establish the rates of application of MeJa that can sufficiently loosen the berries for mechanical harvesting without inducing preharvest fruit drop.

The mechanisms involved in the induction of abscission in response to MeJa are not well understood. In the current study, MeJa-induced fruit abscission responses in blueberry were partly mediated by changes in ethylene biosynthesis because application of AVG, an ethylene biosynthesis inhibitor, attenuated the fruit drop response to MeJa. Consistent with this observation, MeJa-induced fruit drop in citrus was associated with an increase in ethylene evolution (Hartmond et al., 2000). These data suggest that MeJa may regulate abscission responses, at least partly, by inducing ethylene biosynthesis.

Ethephon applications, where effective, generally resulted in the abscission of immature fruit (green and pink) along with the mature fruit. Abscission of young leaves was also observed in response to ethephon application. Ethephon is known to be a non-selective inducer of abscission responses in other crops such as citrus (Malladi and Burns, 2008; Yuan and Burns, 2004). The application of MeJa, especially at high rates (20 mM or greater), resulted in substantial yellowing of leaves. Exogenous MeJa applications are known to induce chlorophyll degradation, and jasmonates can promote the progression of chlorophyll degradation mechanisms and senescence in plant systems (He et al., 2002; Saniewski et al., 1987; Ueda and Kato, 1980; Wasternack, 2007). In fact, applications of coronatine, a compound with functional similarities to the jasmonates, resulted in lower chlorophyll content and leaf yellowing, symptoms that were ameliorated later in the season in citrus (Burns et al., 2003). It may be likely that high rates of application of MeJa

(20 mM or greater) lead to chlorophyll degradation and trigger senescence mechanisms in leaves. Additionally, high rates of MeJa application (20 mM or greater) resulted in necrosis of leaf tips and margins and leaf drop. Similarly, MeJa applications higher than 10 mM induced leaf drop in citrus (Hartmond et al., 2000). Preliminary evaluations over multiple years do not suggest that the growth or productivity of the blueberry plants is adversely affected by MeJa applications. However, additional studies, including analysis of lower rates of application of ethephon and MeJa or their combinations, are required to determine if the incidence of phytotoxicity symptoms, leaf drop, and immature fruit abscission can be mitigated while achieving substantial fruit loosening.

A critically important aspect of ethephon and MeJa-induced fruit detachment in blueberry was that it occurred primarily at the point of attachment of the pedicel to the peduncle. A large majority of the fruit (greater than 95%) that dropped in response to these abscission agent applications had the pedicel attached to the berry (stemmy berry), a pattern observed consistently over multiple experiments. These data indicate that the abscission zone at the pedicel/peduncle junction is more sensitive to abscission agent applications in blueberry. Also, the FDF (measured at the attachment of the pedicel to the berry) was often unaffected by the application of ethephon or MeJa, except in the study with T-451. In fruit intended for the fresh fruit market, the presence of the pedicel on the berry is considered to be a defect that reduces the quality of the fruit and is therefore undesirable (USDA, 1995). Hence, effective de-stemming to remove the pedicel from the berry will be a key step during post-harvest processing if the fruit are to be mechanically harvested with the aid of ethephon or MeJa.

Together, the data from the current study indicate that ethephon and MeJa applications have the potential to induce rapid fruit detachment in rabbiteye and southern highbush blueberry. However, the application of these abscission agents was associated with leaf phytotoxicity, leaf drop, immature fruit drop, and detachment of the pedicel along with the fruit. Hence, further research is required to determine the rates of application of these compounds that can induce fruit loosening for mechanical harvesting without the described symptoms.

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