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Gibberellic Acid Inhibits Floral Bud Induction and Improves 'Bing' Sweet Cherry Fruit Quality

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***Abstract*. This paper reports on the potential of gibberellic acid (GA_3 and GA_{4+7}) to reduce sweet cherry (*Prunus avium* L.) floral bud induction and balance fruit number and improve fruit quality in the season following application. In 2003, GA_3 was applied to 'Bing'/'Gisela 1' trees at 50 and 100 mg·L^{-1} at the end of stage I of fruit development, end of stage II, and on both dates. These treatments were compared to the industry standard application of 30 mg·L^{-1} applied at the end of stage II and an untreated control. Fruit quality was evaluated in the year of application (i.e., nontarget crop) and return bloom, fruit yield and quality were assessed in the subsequent season (2004). In 2003, GA_3 delayed fruit maturity proportional to rate. In 2004, bloom density and fruit yield were related negatively and linearly to GA_3 concentration. GA_3 reduced the number of reproductive buds per spur and did not affect the number of flowers per reproductive bud. Nonspur flowering at the base of 1-year-old shoots was more inhibited by GA_3 than flowering on spurs. Double applications significantly reduced bloom density and yield versus single applications. Trees treated with two applications of 50 and 100 mg·L^{-1} yielded fruit with 7% and 12% higher soluble solids, 15% and 20% higher firmness, and 7% and 14% greater weight, respectively. However, no treatment improved crop value per tree. In a separate isomer trial, GA_3 and GA_{4+7} were applied to 'Bing'/'Gisela 1' trees at 100 and 200 mg·L^{-1} at both the end of stage I and II in 2004. GA_3 and GA_{4+7} applied at 100 mg·L^{-1} reduced bloom density similarly by 65%. GA_3 was more inhibiting than GA_{4+7} at 200 mg·L^{-1}, reducing bloom density by 92% versus 68%. We observed a 4- to 5-day delay in flowering from both GA formulations at 200 mg·L^{-1}. At both concentrations, GA_3 reduced yield by 71% and 95% versus 34% and 37% reduction by GA_{4+7}. Fruit weight and soluble solids were unaffected but fruit firmness was increased by all treatments (6% to 17%). However, crop value per tree was highest from untreated control because improvements in fruit quality were insufficient to offset reductions in yield. GA_3 shows potential as a novel crop load management tool in productive 'Bing' sweet cherry orchard systems.**

Gibberellic acid (GA_3) applied at about 30 mg·L^{-1} at the beginning of stage III of fruit development is currently a standard application for sweet cherry (*Prunus avium* L.) growers worldwide for improving fruit quality and delaying maturity. Proebsting et al. (1973) reported an increase in 'Rainier' fruit firmness, size and ascorbic acid content and a reduction in anthocyanins with GA_3 applications of 10 to 30 mg·L^{-1} in stage III. More recently, Kappel and MacDonald (2002) reported that single applications of 20 and 30 mg·L^{-1} GA_3 and multiple applications of 10 mg·L^{-1} applied at early stage III to 'Sweetheart' increased fruit firmness by 21%, 19%, and 19% and weight by 12%, 8%, and 10%, respectively. Moreover, the authors reported no benefit to multiple applications versus a single application. Similarly, Facteau et al. (1985) reported significant improvements in fruit weight, firmness and soluble solids from GA_3 application to 'Bing' and 'Lambert', with no difference between multiple and single applications. GA_3 dose was related positively to fruit firmness.

Grower reports and research trials have also shown that GA_3 reduces sweet cherry return bloom when applied during floral bud induction (Bradley and Crane, 1960; Hull and Lewis, 1959; Proebsting and Mills, 1974). Facteau et al. (1989) reported that 10 to 100 mg·L^{-1} of GA_3 reduced return bloom by 21% to 54% when applied at the beginning of stage III. Similar results have been reported for apricot (*P. armeniaca*) (Byers et al., 1990; Southwick et al., 1995), apple (*Malus domestica* Borkh.) (Tromp, 1982) and peach (*P. persica*) (Southwick et al., 1995; Taylor and Geisler-Taylor, 1998). Bradley and Crane (1960) reported that 250 mg·L^{-1} of GA_3 applied at the onset of pit hardening (i.e., early stage II) completely inhibited sweet cherry floral bud induction. Furthermore, in apple, GA_{4+7} is a more potent inhibitor of floral bud induction than GA_3; pure GA_4, in contrast, is ineffective at reducing bloom (Tromp, 1982). Thus far, however, there are no reports on the effects of isomers other than GA_3 on sweet cherry.

In cherry, it was proposed initially that reduced flowering in the year following GA_3 application may be beneficial for increasing the size of young trees (Hull and Lewis, 1959). However, reductions in flowering and fruiting density may also help to balance crop load in modern, high efficiency orchard systems, particularly those based on new clonal, precocious and productive rootstocks such as the Gisela series. Indeed, the development of new crop load management strategies will be critical to sustainable production of high quality fruit in orchards planted with the Gisela series of rootstocks (Whiting and Lang, 2004; Whiting et al., 2005). The manual removal of fruiting spurs and chemically thinning blossoms have shown promise as crop load management tools (Whiting and Ophardt, 2005; Whiting et al., 2006). Gibberellic acid applications during floral bud induction may also be an effective tool.

Thus far, there are no reports on the effect of GA_{4+7} on sweet cherry floral bud initiation, or on the effect of any GA isomer at different concentrations and timings on fruit yield and quality in the season subsequent to application. The objective of this research was to evaluate the potential of GA_3 and GA_{4+7} to reduce floral bud induction and improve fruit quality in the season following application in 'Bing' sweet cherry grafted on the precocious, and size-controlling rootstock 'Gisela 1' (*P. fructicosa* ×*P. avium*).

Materials and Methods

Plant material and experimental design. All trials were conducted at Washington State University's Roza experimental farm north of Prosser, Wash. (46.2°N, 119.7°W), in a mature (9-year-old in 2003) 'Bing'/'Gisela 1' sweet cherry orchard. Trees, planted in north–south rows, were irrigated weekly from bloom to leaf senescence with low-volume under-tree microsprinklers. Standard orchard management strategies (pruning and pesticide application) were carried out every year.

Each trial was arranged in a randomized complete block design with five single-tree replications. Trees were selected for uniformity of size and cropping potential. Previous cropping history of experimental trees was not recorded. Each treated tree was isolated with at least one guard tree to the N and S. Treatment means were analyzed by radiating regression as described by Elfving and Allen (1987) using the general linear models (GLM) procedure in the statistical analysis system (SAS) program

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(SAS Institute, Cary, N.C.). Figures show lines representing different timings or different GA isomers with a common intercept. Treatment means were also compared by Duncan's test at 0.05 by analysis of variance (Proc GLM).

GA_3 trial. In 2003, GA_3 was applied as dilute sprays to run-off by a hydraulic handgun sprayer to whole trees at 30, 50, and 100 mg·L^{-1} plus 0.1 % v/v Regulaid. A control group received no treatment. Applications were made at the end of stage I of fruit development (beginning of endocarp lignification) (DOY = 133, 13.0 + 0.1 mm fruit diameter), end of stage II of fruit development (fruit color change from green to yellow) (DOY = 159, 18.1 + 0.1 mm diameter) and on both dates. The 30 mg·L^{-1} treatment was only applied at the end of stage II. Fruit sub-samples were collected from all trees on 2 harvest dates (24 June, 2003 and 27 June, 2003) and fruit quality (firmness and diameter, [Firmtech, BioWorks, Inc., Wamego, Kans], color, soluble solids (digital refractometer, [Atago Co., Ltd, Japan]) and weight were determined from a minimum of 100-fruit sub samples per tree. Mean color rating (2 = light red, 3 = red, 4 = dark red, 5 = mahogany) was assessed in 2003 (nontarget crop)

In March 2004, number of reproductive buds per spur was assessed visually on two branches per tree (minimum 50 spurs per tree) and number of flowers per bud was assessed by sectioning buds transversely through the thickest part and counting flowers. At the popcorn stage of flowering, bloom density was determined by counting all flowers on one east- and one west-facing branch per tree. Branch diameter was measured at the base by digital caliper. Fruit set (% available flowers) was obtained by counting fruit on the same branches just before harvest. Whole tree yields were recorded in the orchard at harvest (14 June, 2004). Fruit quality of a minimum 100-fruit subsample was determined as outlined above. Weighted fruit diameter (mm) was determined by the relationship between fruit diameter and the percentage of fruit in that diameter category. Crop value ($/tree) was determined from yield and size relationships and the price per row-size (an industry size designation related to fruit diameter) category.

GA_3 and GA_{4+7} trial. In a separate isomer trial in 2004, GA_3 and GA_{4+7} were applied as dilute sprays to run-off by a hydraulic handgun sprayer to whole trees at 100 and 200 mg·L^{-1} at both the end of stage I (DOY = 124, 12.9 + 0.1 mm fruit diameter) and the end of stage II (DOY = 145, 16.5 + 0.1 mm fruit diameter). Whole-tree yields were recorded in the orchard at harvest. In 2004, untreated trees were harvested (14 June) 6 d before GA-treated trees, which were harvested on the same date (20 June). In 2005 all fruit were harvested on 22 June. Fruit quality was assessed both in 2004 (nontarget crop) and in 2005 (target crop) as outlined above. Bloom density and crop value were also measured in 2005 as outlined above.

Results and Discussion

GA_3 trial. In 2003, GA_3 delayed maturity of the current season crop, as estimated by fruit skin color and firmness, at every concentration (data not shown). Color rating was significantly lower in all GA_3 treatments compared to the control on the first harvest date (24 June). On 24 June, 39% of the control fruit were 'mahogany' (optimum for commercial maturity), whereas 30, 50, and 100 mg·L^{-1} treatments had only 10%, 8.6%, and 2.6% fruit in this category. Fruit soluble solids were lower from all GA_3-treated trees on the first harvest date, though statistically similar to the control. In addition, fruit firmness was higher from all GA_3 treatments; fruit treated with 50 mg·L^{-1} and 100 mg·L^{-1} were 41% and 39% firmer than the control, respectively. In contrast, fruit weight was not affected by any treatment in 2003 (data not shown).

By 27 June, 3 d later, soluble solids had increased compared to the previous harvest date but were similar for all treatments. Fruit firmness remained higher (22% to 42%) for every GA_3 treatment. In addition, color did not reach the percentage of mahogany fruit in the untreated control (58%) by the second harvest date; 30, 50, and 100 mg·L^{-1} treatments had 36%, 22%, and 8% fruit in this category. These data suggest that fruit treated with GA_3 had not achieved commercial maturity by 27 June and that fruit maturation was delayed proportional to rate of GA_3. Proebsting (1973) found similar results on 'Rainier' fruit quality after GA_3 applications—firmness and fruit weight were increased but soluble solids were unaffected. Also, color did not reach the level of the control 7 d later (Proebsting, 1973). Facteau et al. (1985) reported increased 'Bing' and 'Lambert' fruit weight, soluble solids, and firmness after GA_3 applications ranging from 10 to 150 mg·L^{-1} when fruit were picked at similar color. Other studies have documented increased fruit weight after GA_3 treatment on sweet cherry fruit quality (Drake et al., 1978; Kappel and MacDonald, 2002). We hypothesize the fruit quality response to GA_3 will vary for different varieties as well as with various intra-canopy factors such as crop load though these factors have yet to be compared empirically in a single trial.

Little research has investigated the effects of GA on sweet cherry flowering and fruit quality in the following season; instead, studies have focused on fruit quality effects in the current season. In this research, we were particularly interested in evaluating the potential for GA_3 to reduce bloom density and balance crop load in the season subsequent to application. In the subsequent season (2004), 30, 50 and 100 mg·L^{-1} GA_3 reduced bloom density by 5%, 27%, and 38%, respectively and across all application timings. Interestingly, this reduction was evident as differences in the number of reproductive buds per spur rather than the number of flowers per reproductive bud (Table 1). In addition, the number of reproductive buds per spur was related negatively to rate of GA_3. This is of great practical significance for a potential crop load management program using GA_3 because growers can visually assess reproductive buds to determine treatment effects and fruiting density.

Nonspur flowering at the base of 1-year-old shoots was more inhibited by GA_3 than flowering on spurs. GA_3 at 30, 50, and 100 mg·L^{-1} reduced total number of flowers at the base of 1-year-old wood by 45%, 47%, and 87%, respectively (data not shown). Instead of differentiating into reproductive buds, basal nodes were vegetative. Facteau et al. (1989) reported that 20 mg·L^{-1} GA_3 reduced flowers on 1-year-old wood by 35%. Similar negative linear relationships with GA_3 and return bloom have also been reported for 'Loadel' peach (Southwick et al., 1995) and 'Crimson Gold' nectarine (Garcia-Pallas and Blanco, 2001). The mechanism by which GA_3 inhibits floral bud induction is not clear. In apple, gibberellins are thought to increase the vegetative sink strength thereby reducing carbohydrate supply to the reproductive buds (Luckwill and Silva, 1979). Apple seeds are a strong source of gibberellins and have a localized inhibitory effect on flowering (Chan and Cain, 1967). Hoad (1978) reported that more gibberellin is

Table 1. Effect of GA_3 application in 2003 on bloom density (flowers/cm^2), fruit yield (kg), fruit quality (weight, soluble solids, firmness, diameter), and crop value of 10-year-old 'Bing'/'Gisela 1' trees in 2004. Treatments are listed by the GA_3 concentration (mg·L^{-1}) and timing of application (fruit growth stage). Means followed by the same letter are not significantly different within a column (n = 5, $p < 0.05$).

Treatment	Bloom density (flowers/cm^2)	Buds/spur (no.)	Flowers/bud (no.)	value (kg)	value (g)	Soluble Yield (%)	Wt (g/mm)	Fruit solids (mm)	Crop Firmness ($/tree)	Crop diam ($/kg)
Control	42.1 a	3.6 ab	2.5^{NS}	12.8 a	7.3 bc	19.7 bc	275 c	24.7 b	31.66	2.47
30, II	40.1 ab	3.8 a	2.3	10.4 ab	7.4 bc	20.1 abc	276 c	24.8 b	25.85	2.49
50, I	34.8 ab	3.4 ab	2.4	10.4 ab	7.2 c	19.4 c	291 bc	25.0 b	26.33	2.53
50, II	27.1 bc	3.5 ab	2.4	9.6 ab	7.4 bc	20.1 abc	281 bc	24.7 b	24.00	2.48
50, I and II	30.4 abc	3.3 ab	2.4	5.8 bc	7.9 abc	21.2 abc	316 ab	25.7 a	16.15	2.77
100, I	26.7 bc	3.1 b	2.3	4.6 c	8.2 ab	21.6 ab	307 abc	26.3 a	13.70	2.97
100, II	35.6 ab	3.2 ab	2.4	6.3 bc	7.8 abc	20.4 abc	311 abc	25.8 a	17.69	2.81
100, I and II	16.5 c	2.1 c	2.2	4.7 c	8.4 a	22.0 a	329 a	26.3 a	13.82	2.97
p values	0.004	0.0002	0.57	0.004	0.05	0.04	0.01	<0.0001		

exported from apple fruit to spurs in biennial bearing cultivars than in regular-flowering cultivars, concluding that endogenous gibberellins have the same inhibitory effect on flowering as exogenous gibberellin applications do. Similar studies have not been carried out for stone fruit. However, in sweet cherry, gibberellins accumulate in sinks, such as young expanding leaves (Cristoferi and Filiti, 1983). Facteau et al. (1989) suggested that flowers on 1-year-old wood are more inhibited by GA_3 than spur flowers due to the proximity of young leaves.

Timing of GA_3 application is important, presumably in relation to floral bud induction though this has not been empirically evaluated. We are reporting application timing in relation to current season phenology, presuming a synchrony with floral bud initiation. Facteau et al. (1989) reported no effect on sweet cherry floral bud induction from GA_3 application 2 weeks after full bloom and a 26% and 54% reduction in flower buds per spur from a 50 and 100 mg·L^{-1} treatment at the beginning of stage III. Our results show that a double application of 50 mg·L^{-1} and all applications of 100 mg·L^{-1} reduced flowering by 27% and 38%, respectively, compared to the untreated control (Table 1). Regression analysis conducted with a compressed intercept illustrates the effects of application timing on bloom density (Elfving and Allen, 1987). Double applications of GA_3 at the end of stages I and II were more effective at reducing flowering than either of the single applications (Fig. 1A).

Fruit set did not differ significantly among treatments (data not shown); therefore reductions to yield are a direct result of GA_3 applications the previous season. Yield was unaffected by the standard treatment of 30 mg·L^{-1} at the end of stage II or the single applications of 50 mg·L^{-1}. However, a double application of 50 mg·L^{-1} and all applications of 100 mg·L^{-1} reduced yield by 55% and 60%, respectively, compared to the untreated control (Table 1). Double applications of GA_3 at the end of stages I and II were more effective than single applications at reducing yield (Fig. 1B). Moreover, single applications produced similar yield results, irrespective of concentration. Similarly, Proebsting and Mills (1974) reported a 65% yield reduction in the season following 100 mg·L^{-1} GA_3 at the end of stage I and a 56% yield reduction following application at the end of stage II on 'Bing'/Mazzard trees.

Fruit quality in 2004 was improved by GA_3 applications in 2003 (Table 1). This is an indirect effect due to reduced bloom density and yields and the negative relationship between fruit yield and quality (Whiting and Lang, 2004). Double applications of 50 and 100 mg·L^{-1} improved soluble solids by 7% and 12%, and firmness by 15% and 20% respectively. In addition, GA_3 twice-applied at 100 mg·L^{-1} improved fruit weight by 14% (Table 1). In general we documented a positive relationship between [GA_3] applied in 2003 and fruit quality parameters such as firmness, weight, and soluble solids evaluated in 2004 (Fig. 2). For every quality parameter, a double application of GA_3 led to significant improvements. This again is a result of there being fewer flowers and fruit per tree from double applications (Fig. 1). A single application at the end of stage II consistently resulted in poorer fruit quality than other timings. We found significant improvements in fruit diameter from the double application of 50 mg·L^{-1} and all applications of 100 mg·L^{-1} (Table 1); this too is a result of reduced crop load in those trees.

An important analysis for any series of treatments which affect yield and quality is the economic impact of each treatment. Crop value ($/tree and $/kg) was estimated from the relationship between yield per fruit size category and the price per size category (G. Allan, personal communication). In general, crop value per kg was higher from treated trees compared to the control due to improvements in fruit diameter and the higher prices paid for large fruit (Table 1). Value per kg was increased 12% by a double application of 50 mg·L^{-1} and by about 18% from applications of 100 mg·L^{-1}, irrespective of timing. However, despite significant improvements in fruit quality from GA_3 applications and higher crop value per kg, crop value per tree was lower for each treatment, compared to the untreated control (Table 1). This is because improvements in fruit size were insufficient to compensate for significant reductions in yield. Across timings, 30, 50, and 100 mg·L^{-1} GA_3 reduced tree yield by 19%, 33%, and 59%, respectively. However, fruit weight was improved only by 1%, 2%, and 10%, respectively. Crop value data illustrate the practical challenge of balancing crop load via reductions in flowering density (i.e., yield potential). In addition, given the current price structure for sweet cherries, growers are

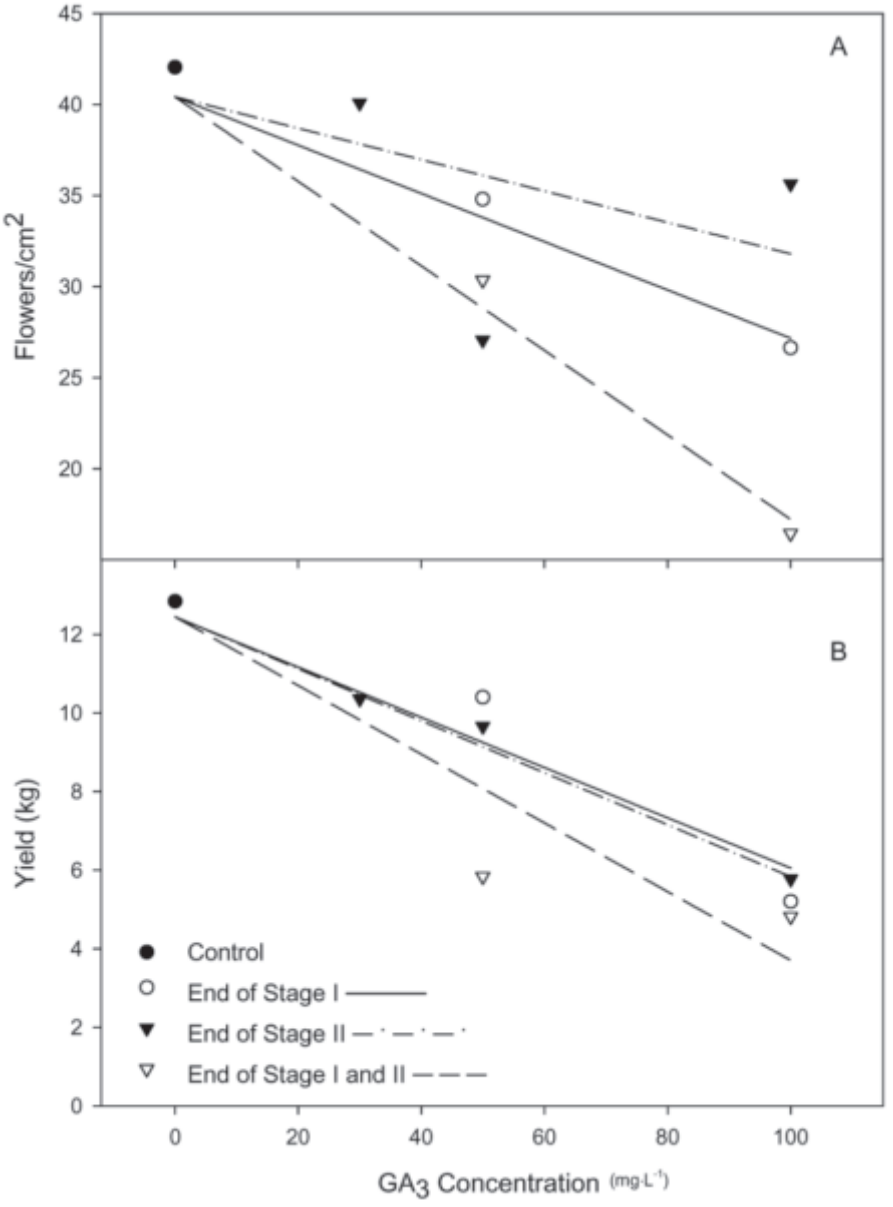

Fig. 1. Effect of GA_3 concentration applied at different timings (2003) on bloom density (number of flowerssquare centimeter limb cross sectional area) (**A**) (2004) and fruit yield (**B**) (2004). Legend in **B** also applies to **A**. (**A**) Stage I: y = 40.4 – 0.132x. Stage II: y = 40.4 – 0.086x. Stage I and II: y = 40.4 – 0.232x. (**B**) Stage I: y = 12.4 – 0.066x. Stage II: y = 12.4 – 0.064x. Stage I and II: y = 12.4 – 0.087x.

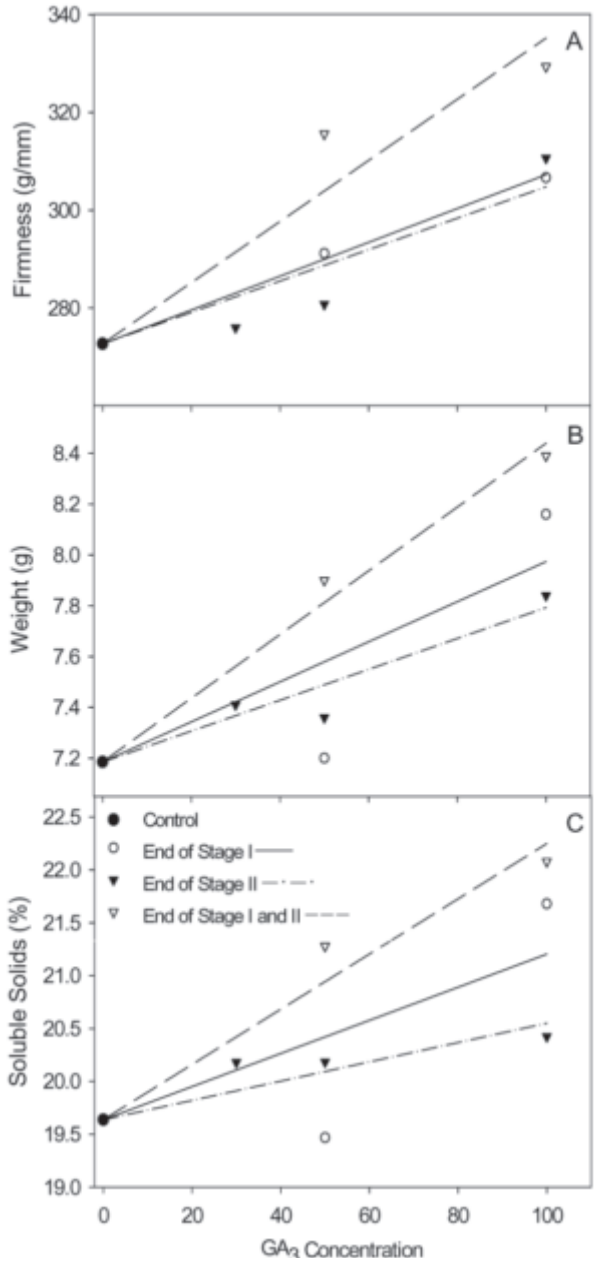

Fig. 2. Effect of GA_3 concentration and application timing in 2003 on firmness (g/mm) (**A**), fruit weight (g) (**B**), and soluble solids (%) (**C**) in 2004. Partial r2 = 0.45, 0.39, 0.31. Legend in **C** also applies to **A** and **B**. (**A**) Stage I: y = 272.7 + 0.346x. Stage II: y = 272.7 + 0.321x. Stage I and II: y = 272.7 + 0.625x. (**B**) Stage I: y = 7.18 + 0.007x. Stage II: y = 7.18 + 0.006x. Stage I and II: y = 7.18 + 0.013x. (**C**) Stage I: y = 19.6 + 0.016x. Stage II: y = 19.6 + 0.009x. Stage I and II: y = 19.6 + 0.026x.

rewarded for producing high yields of moderate size fruit rather than lower yields of very high quality fruit. This agrees with previous analyses of sweet cherry crop value (Whiting et al., 2006). In the current trial, untreated trees were not heavily cropped and fruit quality was good. For example, only about 0.3% fruit were smaller than 21.4 mm—a clear indication of a well-balanced crop load. In contrast, for example, heavily cropped 'Bing'/'Gisela 5' trees have yielded most of fruit in this smallest size category (Whiting et al., 2006). We hypothesize that on more productive, source-limited trees, GA_3 applications would benefit crop value in the subsequent season. On a productive Bing/'Gisela 5' tree yielding 25 kg, GA_3 application (50 to 100 mg·L^{-1}) would reduce yield 58% to about 10.4 kg, and presumably produce high fruit quality similar to the 30 mg·L^{-1} treatment (Table 1). Moreover, Whiting and Ophardt (2005) suggested that a 50% crop load reduction on 'Bing'/'Gisela 5' is necessary for optimum fruit growth. Concentrations above 50 mg·L^{-1} may excessively inhibit flowering depending on the scion–rootstock combination in mature bearing orchards but may have potential application in young 'Gisela'-rooted orchards where growers wish to eliminate flowering and fruiting in the first 2 years following planting to establish the canopy.

In 2004, floral meristem initiation for the 2005 crop was related linearly and negatively to 2004 yields (data not shown). Yield reductions from the double application of 50 mg·L^{-1} and all timings of the 100 mg·L^{-1} (Table 1) resulted in significantly higher floral meristems per bud than the single timing of 50 and 30 mg·L^{-1} treatments. Moreover, the control treatment had significantly fewer floral meristems per bud compared to all treatments. Guimond et al. (1998) reported that floral initiation for 'Bing' sweet cherry in the Pacific Northwest takes place after harvest (mid to late July). Therefore, trees with significantly higher crop load likely experienced a reduction in carbohydrate supply, which affected floral initiation. In contrast, floral bud induction was not related closely to the current season's yields. The number of fruit buds per spur in the double application of 100 mg·L^{-1} treatment was significantly higher than the untreated control; all other treatments were statistically similar. In 2005, average yield from the 100 mg·L^{-1} treatment (double application) was 155% higher than the untreated control and was four times higher than the same trees in the previous season. Similarly, Whiting and Lang (2004) reported that current season canopy fruit-to-leaf area ratio had no effect on the number of buds per spur and a negative linear relationship existed between floral meristems per bud and the current season's crop load on hand-thinned 'Bing'/'Gisela 5' trees.

Isomer trial, 2004–05. Applications of GA_3 and GA_{4+7} at 100 and 200 mg·L^{-1} in 2004 reduced return bloom and yield in 2005, compared to the control. Fruit set was similar among all treatments (data not shown). At 100 mg·L^{-1}, GA_3 and GA_{4+7} reduced return flowering by about 65% and 66%, respectively. At 200 mg·L^{-1} GA_3 nearly eliminated return flowering, reducing bloom by about 93%. In contrast, GA_{4+7} was not as inhibiting, reducing flowering by 68% (Table 2). Regression analyses show that GA_3 is more inhibiting to sweet cherry floral bud induction than GA_{4+7}—the slope of the regression with GA_3 is 58% greater than the slope of the GA_{4+7} response (Fig. 3). These results differ from previous work in apple, in which GA_{4+7} reduced approximately 35% more flower clusters than GA_3 (Tromp, 1982). Tromp (1982) also reported that the GA_4 isomer alone was ineffective at reducing flowers while GA_7 was most inhibiting to flower development. Oliveira and Browning (1993) reported that GA_3 was more inhibiting to floral bud induction than GA_7, which was in turn more inhibiting than GA_4 and suggested that increased hydroxylation in isomer structures resulted in a stronger effect on flower reduction as well as shoot growth promotion.

Interestingly, both GA_3 and GA_{4+7} applied at 200 mg·L^{-1} delayed flowering by approximately 5 d in spring, 2005. However, this delay had no effect on fruit maturity. Similarly, peach bloom was delayed by 14 d after GA_3 application at 200 mg·L^{-1} in the previous season (Corgan and Widmoyer, 1971). This delay may be attributable to increased competition

Table 2. Effect of GA_3 and GA_{4+7} applications in 2004 on bloom density (flowers/cm^2 limb cross-sectional area), fruit yield (kg/tree), fruit quality (weight, soluble solids, firmness, diameter), and crop value from 11-year-old 'Bing'/'Gisela 1' trees in 2005. Treatments are listed by the GA isomer and concentration (mg·L^{-1}). Means followed by the same letter are not significantly different within a column (n = 5, p = 0.05).

Treatment	Bloom density (flowers/cm^2)	Buds/spur (no.)	Flowers/bud (no.)	Yield value (kg)	Fruit value (g)	Soluble solids (%)	Wt (g/mm)	Fruit Firmness (mm)	Crop value (\$/tree)	Crop diam (\$/kg)
Control	29.6 a	3.0 a	2.5 a	8.8 a	10.6^{NS}	22.9^{NS}	307 c	28.4^{NS}	30.41	3.44
GA_3, 100	10.3 b	1.7 b	2.2 b	2.6 bc	10.1	25.9	360 a	28.2	8.67	3.38
GA_3, 200	2.2 c	0.6 c	2.0 c	0.5 c	10.5	23.9	352 ab	27.7	1.59	3.31
GA_{4+7}, 100	10.1 b	2.1 b	2.2 b	5.8 ab	10.6	24.6	325 bc	28.1	19.77	3.41
GA_{4+7}, 200	9.2 b	2.2 b	2.2 b	5.6 ab	10.6	24.0	328 bc	28.5	19.25	3.44
p values	0.0001	0.0001	0.0001	0.0003	0.65	0.13	0.01	0.86		

among vegetative and reproductive growth after GA application (Corgan and Widmoyer, 1971). In addition, we observed <5% flowers with reduced petal size in response to 200 mg·L^{-1} of both GA_3 and GA_{4+7}. Garcia-Pallas and Blanco (2001) reported elongated flowers on 'Crimson Gold' nectarine as a result of GA_3 application, though no negative effects on fruit shape were reported.

Reductions in flowering from GA treatment led to lower fruit yield in 2005. GA_3 and GA_{4+7} applied at 100 mg·L^{-1} reduced yield by 71% and 34%, respectively. Moreover, GA_3 and GA_{4+7} at 200 mg·L^{-1} reduced yield by 94% and 37%, respectively. (Table 2). However, with the exception of fruit firmness, quality was not significantly better from GA-treated trees, despite about 18-fold differences in yield (Table 2). Firmness was improved by each treatment though only statistically so by GA_3 at both concentrations. Fruit weight, soluble solids and diameter were excellent overall (mean = 10.45 g, 24.6% and 28.2 mm, respectively) and unaffected by treatment. In addition, a majority of the fruit in all treatments was between 30 mm and 28.2 mm diameter – a premium size category. Trees treated with GA_{4+7} at 200 mg·L^{-1} yielded the largest percentage of fruit over 26.6 mm (82.4%), followed by the control (79.8%) (data not shown). GA_3 application at 100 mg·L^{-1} resulted in the largest percentage of fruit in the 24.2 to 26.6 mm size range (34.4%) compared to other treatments. Overall, less than 2% of fruit were smaller than 22.6 mm (i.e., not saleable on the fresh market). This is likely due to overall low yields (8.8 kg for control) and high canopy leaf area-to-fruit ratio, though leaf area was not empirically determined for this trial. At 10.6 g per fruit in the untreated control, fruit weight was 10% heavier than a heavily-thinned crop of 'Bing' on 'Gisela 5' from previous research (Whiting and Lang, 2004). We conclude that fruit growth from untreated control trees was not limited by assimilate supply and therefore, difficult to improve upon. As expected then, crop value per tree was highest from the untreated control, due to the significantly higher yields than GA-treated trees. In addition, no treatment improved significantly crop value per kg.

In conclusion, both GA_3 and GA_{4+7} inhibit sweet cherry floral bud induction and show potential to reduce blossom density and yield and improve fruit quality in the season following application. GA_3 was more inhibiting to sweet cherry flower initiation than GA_{4+7}. Concentrations of 100 and 200 mg·L^{-1} appear impractical commercially for 'Bing' due to excessive reductions in yield and crop value per tree. In addition, we observed a biennial bearing pattern in trees that had reduced crop load in the previous season; this was more pronounced in higher GA concentration treatment groups, and does not appear to be an issue for concentrations ranging from 30 to 50 mg·L^{-1}. In this trial, all 2003 GA_3 treatments improved crop value per kg, but due to good fruit quality and higher yields in the control, no treatment improved crop value. However, we hypothesize that GA_3 applied at about 50 mg·L^{-1} would improve crop value from heavily cropping trees such as mature 'Bing'/'Gisela 5' trees which can yield >30 kg per tree (Whiting and Lang, 2004). Results presented in this paper suggest that further research in crop load management by GA_3 is warranted. However, caution must be taken when interpreting the results of these trials. Each trial was conducted once on one variety/rootstock combination and the results may not apply to other varieties. To develop a reliable crop load management program using GA_3, much more research is needed to investigate the effects of gibberellins on return bloom and fruit quality and yield of heavily cropping variety and rootstock combinations.

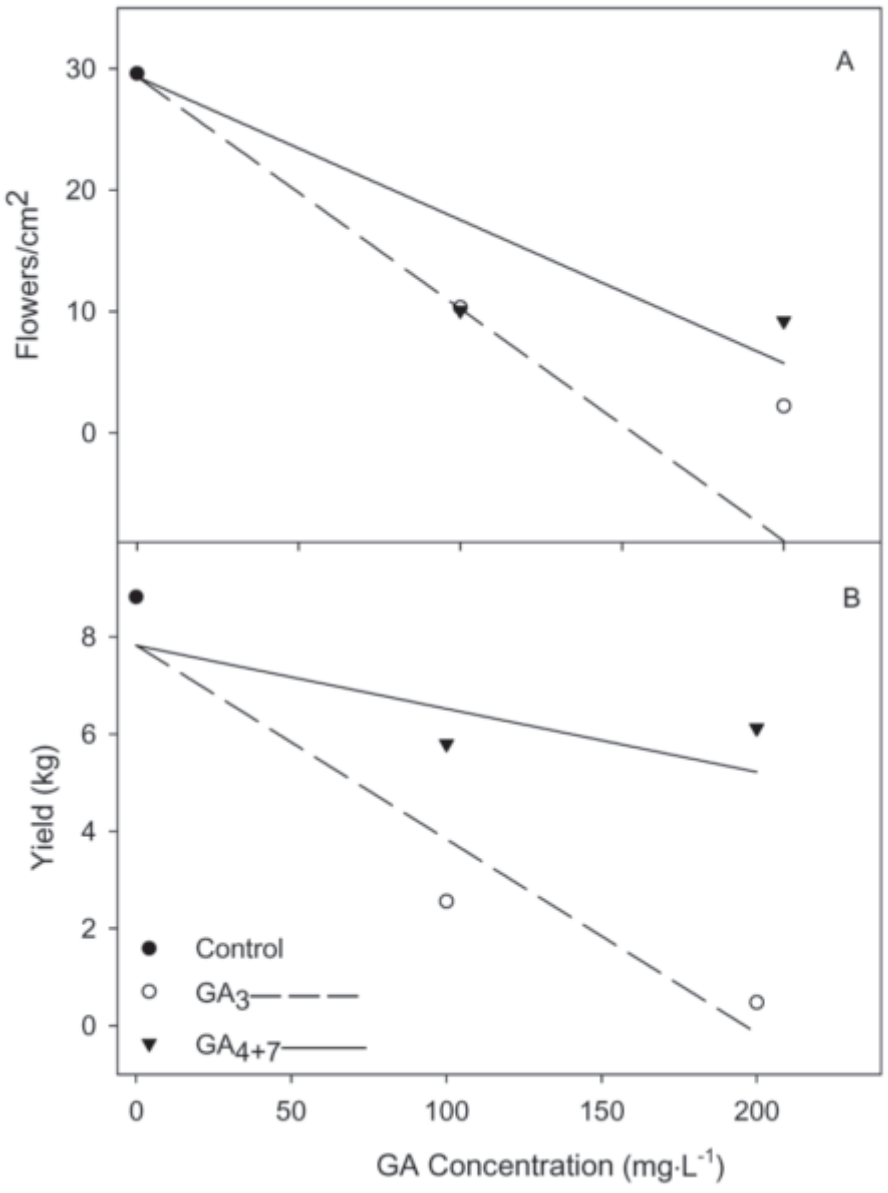

Fig. 3. Relationship of GA isomer and concentration applied in 2004 on bloom density (number of flowers per square centimeter limb cross sectional area) (**A**) and yield (**B**) in 2005. Partial r^2 = 0.74, 0.45. Legend in **B** also applies to **A**. (**A**) GA_3: y = 29.3 – 0.19x. GA_{4+7}: y = 29.3 – 0.12x. (**B**) GA_3: y = 7.82 – 0.04x. GA_{4+7}: y = 7.82 – 0.01x.

Literature Cited

Bradley, M.V. and J.C. Crane. 1960. Gibberellin-induced inhibition of bud development in some species of prunus. Science. 131:825–826.

Byers, R.E., D.H. Carbaugh, and C.N. Presley. 1990. The influence of bloom thinning and GA sprays on flower bud numbers and distribution in peach trees. J. Hort. Sci. 65(2):143–150.

Chan, B.G., and J.C. Cain. 1967. The effect of seed formation on subsequent flowering in apple. Proc. Amer. Soc. Hort. Sci. 91:63–68.

Corgan, J.N. and F.B. Widmoyer. 1971. The effects of gibberellic acid on flower differentiation, date of bloom, and flower hardiness of peach. J. Amer. Soc. Hort. Sci. 96:54–57.

Cristoferi, G. and N. Filiti. 1983. Translocation and accumulation of labeled gibberellic acid into fruitlets and shoot apices of sweet cherry. Acta Hort. 139:161–170.

Drake, S.R., E.L. Proebsting, G.H. Carter, and J.W. Nelson. 1978. Effect of growth regulators on ascorbic acid content, drained weight and color of fresh and processed 'Rainier' cherries. J. Amer. Soc. Hort. Sci. 103(2):162–164.

Elfving, D.C. and O.B. Allen. 1987. Effect of gibberellin A_{4+7} applications on 'Golden Delicious' fruit russet. Crop Res. 27:11–18.

Facteau, T.J., K.E. Rowe, and N.E. Chestnut. 1989. Flowering in sweet cherry in response to application of gibberellic acid. Scientia Hort. 38:239–245.
Facteau, T.J., K.E. Rowe, and N.E. Chestnut. 1985. Firmness of sweet cherry fruit following multilple applications of gibberellic acid. J. Amer. Soc. Hort. Sci. 110(6):775–777.
Garcia-Pallas, I. and J.V.A. Blanco. 2001. The inhibition of flower bud differentiation in 'Crimson Gold' nectarine with GA_3 as an alternative to hand thinning. Scientia Hort. 90:265–278.
Guimond, C.M., P.K. Andrews, and G.A. Lang. 1998. Scanning electron microscopy of floral initiation in sweet cherry. J. Amer. Soc. Hort. Sci. 123(4):509–512.
Hoad, G.V. 1978. The role of seed derived hormones in the control of flowering in apple. Acta Hort. 80:93–103.
Hull, J. and L.N. Lewis. 1959. Response of one-year-old cherry and mature bearing cherry, peach and apple trees to gibberellin. Amer. Soc. Hort. Sci. 74:93–101.
Kappel, F. and R.A. MacDonald. 2002. Gibberellic acid increases fruit firmness, fruit size, and delays maturity of 'Sweetheart' sweet cherry. J. Amer. Pomol. Soc. 56:219–222.
Luckwill, L.C. and J.M. Silva. 1979. The effects of daminozide and gibberellic acid on flower initiation, growth and fruiting of apple cv Golden Delicious. J. Hort. Sci. 54:217–223.
Oliveira, C.M. and G. Browning. 1993. Gibberellin structure-activity effects on flower initiation in mature trees and on shoot growth in mature and juvenile *Prunus avium*. Plant Growth Regulat. 13:55–63.
Proebsting, E.L., G.H. Carter, and H.H. Mills. 1973. Quality improvement in canned 'Rainier' cherries (*P. avium* L.) with gibberellic acid. J. Amer. Soc. Hort. Sci. 98:334–336.
Proebsting, E.L. and H.H. Mills. 1974. Time of gibberellin application determines hardiness response of 'Bing' cherry buds and wood. J. Amer. Soc. Hort. Sci. 99:464–466.
Southwick, S.M., K.G. Weis, and J.T. Yeager. 1995. Controlling cropping in 'Loadel' cling peach using gibberellin: Effects on flower density, fruit distribution, fruit firmness, fruit thinning, and yield. J. Amer. Soc. Hort. Sci. 120:1087–1095.
Taylor, B.H. and D. Geisler-Taylor. 1998. Flower bud thinning and winter survival of 'Redhaven' and 'Cresthaven' peach in response to GA_3 sprays. J. Amer. Soc. Hort. Sci. 123(4):500–508.
Tromp, J. 1982. Flower-bud formation in apple as affected by various gibberellins. J. Hort. Sci. 57:277–282.
Whiting, M.D. and G.A. Lang. 2004. 'Bing' sweet cherry on the dwarfing rootstock 'Gisela 5': Thinning affects fruit quality and vegetative growth but not net CO_2 exchange. J. Amer. Soc. Hort. Sci. 129:407–415.
Whiting, M.D., D. Ophardt, O. Lenahan, and D. Elfving. 2005. Managing sweet cherry crop load: new strategies for a new problem. Compact Fruit Tree. 38:52–58.
Whiting, M.D. and D. Ophardt. 2005. Comparing novel sweet cherry crop load management strategies. HortScience 40(5):1271–1275.
Whiting, M.D., D. Ophardt, and J.R. McFerson. 2006. Chemical blossom thinners vary in their effect on sweet cherry fruit set, yield, fruit quality, and crop value. HortTechnology 16:66–70.