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Sweet Cherry Fruit Firmness and Postharvest Quality of Late-maturing Cultivars Are Improved with Low-rate, Single Applications of Gibberellic Acid

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Abstract. **Sweet cherry (*Prunus avium* L.) producers in the Pacific Northwest have devoted considerable acreage to late-maturing cultivars. By using these cultivars to extend the harvest window, producers avoid lower returns associated with cherries harvested during the peak period (i.e., midseason) when supplies are overly abundant. Over several years, we evaluated preharvest applications of gibberellic acid (GA_3) between 10 and 100 ppm (a.i.) on the late-maturing sweet cherry cultivars Lapins, Skeena, Staccato, and Sweetheart. Individual trials examined the timing of GA_3 applications and/or rate on fruit quality attributes at harvest and after 4 weeks of cold storage at 0 °C. The influence of GA_3 timing and/or rate on sweet cherry skin color and harvest delay was also evaluated. Multiple applications split between the end of Stage II (pit hardening) and mid-Stage III (final fruit swell) of fruit development did not improve fruit quality attributes or delay skin color development of 'Skeena' and 'Sweetheart' compared with equivalent concentrations applied once at the end of Stage II. Low concentrations (between 10 and 25 ppm) consistently improved fruit firmness (FF) of all cultivars by 10% to 43%. No further improvements in FF were observed when rates exceeded 25 ppm. Skin color development was retarded by GA_3 but did not respond in a consistent manner to increasing rate. Fruit size was not uniformly increased by GA_3. In trials where GA_3 had a positive effect on fruit size, the effect was observed at low concentrations and was not further improved with increasing rate. A cultivar-dependent response to GA_3 was observed for return bloom. 'Skeena' reproductive buds per fruiting spur and flowers per floral bud in years after treatment were unaffected by GA_3 concentration. On the contrary, the number of flowers per bud of 'Lapins' was significantly reduced to 79% and 38% of control levels for 50 and 100 ppm GA_3, respectively. At 100 ppm, GA_3 additionally limited the number of reproductive buds returning on fruiting spurs of 'Lapins'. GA_3 reduced stem browning and surface pitting disorder of 'Sweetheart' and 'Lapins' after 4 weeks of cold storage at 0 °C; however, these effects were optimized at 25 ppm. Respiration rate and weight loss were unaffected by GA_3 at harvest or after 2 and 4 weeks of cold storage. Unidentified endogenous factors that regulate FF and are inducible by GA_3 appear to be largely responsible for improved resistance to pitting. Collectively, the results demonstrate high sensitivity of cherry FF and skin color to GA_3. Split applications did not provide further harvest delays or affect any of the attributes evaluated, possibly because low rates (20 ppm) applied at the first timing were sufficient to saturate the response. In general, fruit quality of late-maturing cultivars of sweet cherry was improved by low rates of GA_3 applied in a single application at the end of pit hardening.**

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Sweet cherry production in the Pacific Northwest (PNW) has increased roughly 2-fold over the last decade. Despite high consumer demand for fresh cherries, a short postharvest life and oversupply during 'Bing' harvest timing can limit returns paid to orchardists. Subsequently, sweet cherry producers have diversified with early- and late-maturing cultivars to expand the harvest window. In recent years, record sweet cherry crops have incentivized production of late-maturing cherries, which allow time for excessive midseason supplies to diminish. In fact, 61% of all cherry trees planted in Oregon between 1999 and 2005 were late-maturing cultivars (U.S. Department of Agriculture, National Agricultural Statistics Service, 2006); however, recouping higher returns for these cultivars is contingent on exceptional fruit quality at harvest and, particularly, after postharvest cold storage and transportation to export markets.

GA_3 has been shown to improve fruit quality of sweet cherries. The most pronounced and consistent effect of GA on sweet cherry fruit is higher FF (Basak et al., 1998; Clayton et al., 2003; Facteau, 1982a; Facteau et al., 1985a; Kappel and MacDonald, 2002, 2007; Looney and Lidster, 1980; Proebsting and Mills, 1973). Cherry fruit size responded positively to GA_3 (Facteau, 1982a; Facteau et al., 1985b; Kappel and MacDonald, 2002, 2007), although not all studies have observed a size response (Clayton et al., 2003; Facteau et al., 1985a; Looney and Lidster, 1980). In some cases, the effect of GA_3 on fruit size appears to be indirect; attributed to retarded skin color development that grants GA_3-treated fruit additional time to mature on the tree relative to untreated fruit (Choi et al., 2002). Skin pigmentation of 'Lambert' and 'Bing' fruit was significantly delayed in proportion to GA_3 rate (Facteau et al., 1985a). The use of GA_3 to further delay harvest timing of late-maturing cultivars is compelling; however, few studies have characterized cherry fruit and tree response to GA; of those studied, the emphasis has been on 'Sweetheart' (Horvitz et al., 2003; Kappel and MacDonald, 2002, 2007) and 'Lapins' (Choi et al., 2002). Although similar conclusions were reached for these two genotypes, we are unaware of any study that has assessed the response of 'Skeena' to GA_3, a cultivar that has been widely adopted by producers in the PNW. Indeed, response of sweet cherry to preharvest GA_3 applications has been shown to be cultivar-dependent (Usenik et al., 2005). Choi et al. (2002) documented an increase in FF and delayed maturation of two late-season genotypes (135-27-17 and 'Lapins') treated with GA_3 but no effects on the early-maturing varieties 'Merpet' and 'Celeste'.

Commercial application of GA_3 occurs near the end of Stage II of fruit development, i.e., pit hardening, although a recent study demonstrated that GA_3 efficacy did not depend on fruit development within a 3-week period surrounding pit hardening (Kappel and MacDonald, 2007). Moreover, split applications of GA_3 did not improve fruit quality compared with single applications at the same rate for 'Bing' and 'Lambert' (Facteau et al., 1985a) or 'Sweetheart' (Kappel and MacDonald, 2002), implying that timing of treatment application has little effect on fruit response. Few studies have examined incremental rates of GA_3 between 10 and 50 ppm (Facteau et al., 1985a; Horvitz et al., 2003; Kappel and MacDonald, 2002). Horvitz et al. (2003) observed a GA_3 rate response between 10 and 30 ppm on 'Sweetheart' FF; Kappel and MacDonald (2002) did not. Higher rates of GA_3 (100 ppm or greater) were associated with arrested floral bud induction

(Bradley and Crane, 1960; Facteau et al., 1989; Oliveira and Browning, 1993). Although high rates of GA_3 have been investigated as a cropload management strategy for 'Bing' the season after application (Lenahan et al., 2006; Proebsting and Mills, 1974), significantly lower return bloom severely reduced crop value when different isomers of GA (GA_3 or $GA_{4/7}$) were applied at 100 and 200 ppm (Lenahan et al., 2006). 'Bing', however, is not regarded as a highly productive variety, unlike several of the self-fertile, precocious, and productive late-season cultivars that produce a large proportion of undersized fruit of poor quality during high cropload years (Einhorn et al., 2011). Potentially, different cultivars may respond differently to high rates of GA_3.

There is little information available on the influence of GA_3 on postharvest fruit quality of sweet cherry (Clayton et al., 2003; Horvitz et al., 2003; Özkaya et al., 2006), especially late-maturing cultivars (Horvitz et al., 2003). 'Sweetheart' cherries treated with GA_3 at 10 or 30 ppm were significantly firmer and had numerically less stem browning (SB) at the end of cold storage than untreated fruit; the effects were rate-dependent (Horvitz et al., 2003). GA lengthened the storability of 'Bing' (Zhang and Whiting, 2011b) and reduced incidence of surface pitting of 'Lambert' (Facteau and Rowe, 1979) and 'Bing' (Clayton et al., 2003; Drake et al., 1991) in severe pitting years. Surface pitting is the leading cause for product rejection and price adjustments in both domestic and international markets. Pits are defined as irregular, sunken areas on the surface of the fruit (Porritt et al., 1971) caused by mechanical impact or compression during harvest, processing, and transportation (Thompson et al., 1997). Surface pits are typically indiscernible before 1 to 2 weeks of storage in low temperatures. The effect of GA_3 on pitting susceptibility of late-maturing cultivars has not been studied yet.

Our objective was to determine the response of fruit quality attributes of late-maturing sweet cherry cultivars to intermediate (10 to 40 ppm) and high (50 to 100 ppm) preharvest rates of GA_3 both at harvest and after postharvest storage at low temperature. Additionally, we compared equivalent rates of GA_3 applied either as split applications or a single application on 'Sweetheart' and 'Skeena' fruit quality.

Materials and Methods

Research plots were selected in commercial orchards in Oregon's Wasco and Hood River counties, with the exception of one trial site located at the Oregon State University's Mid-Columbia Agricultural Research and Extension Center (MCAREC) in Hood River, OR. Treatments were either applied to entire scaffold limbs (one scaffold per tree) or to whole canopies, depending on the experiment. All experimental units were arranged in randomized complete block designs (RCBDs); whole trees were blocked spatially and scaffold limbs were blocked on basal limb circumference. The level of replication varied with individual experiments. Solutions (ppm) of GA_3 (ProGibb 40% WSG; Valent USA Corp., Walnut Creek, CA) were supplemented with 0.1% (v:v) nonionic surfactant (Silwet L-77; Helena Chemical Co., Collierville, TN) and applied to achieve uniform, complete coverage (i.e., sprayed to drip). Applications to scaffold limbs were made with a CO_2-pressurized hand gun sprayer (Model D Less Boom; Bellspray, Inc., Opelousas, LA). Whole canopies were sprayed with a hydraulic pressurized handgun. For all trials in 2010 and 2011, an unsprayed control was compared with a H_2O + surfactant (0 ppm GA_3) treatment to evaluate the effects of the surfactant alone on fruit response. There were no differences between the unsprayed control and the H_2O + surfactant treatment for any of the response variables measured; therefore, 2012 trials did not include a H_2O + surfactant treatment, and the data from this treatment were omitted from 2010 and 2011 results. To evaluate late application timing at higher GA_3 rates, single or split applications were made. For all single application treatments, and the first application of split application treatments, GA_3 was applied just after pits were fully hardened (i.e., end of Stage II of fruit development) when fruit reached "straw" color. The second application of split application treatments was applied during mid-Stage III of fruit development. In Trials 1 to 3, fruit were harvested at commercial timing. In Trials 4 and 5, treatments were harvested when fruit skin color attained an average, pre-determined value.

Trial 1 (2010–11). In 2010, secondary or tertiary scaffold limbs of seventh-leaf 'Skeena'/Gisela 6 cherry trees trained to a steep leader system were selected based on their basal circumference (measured at a distance of 10 cm from their attachment to the trunk) in a commercial orchard in Parkdale, OR (lat. 45.49° N, long. 121.58° W). A total of 108 scaffolds were selected (one per tree) and blocked on circumference by ranking scaffolds from smallest to largest forming 12 replicates (i.e., Replicate 1 comprised the nine smallest limbs; Replicate 12 comprised the nine largest limbs). Nine treatments were randomized within replicates to reduce error associated with limb size (i.e., sweet cherry cropload does not consistently hold a positive relationship to limb size, and in some cases, smaller limbs can "overset" fruit, thereby limiting fruit quality): 1) 0 ppm GA_3 (untreated); 2) 0 ppm GA_3 (H_2O plus surfactant); 3) 20 ppm GA_3 applied in a single application; 4) 30 ppm GA_3 applied in a single application; 5) 30 ppm GA_3 applied in a double application (20 ppm at straw color + 10 ppm mid-Stage III); 6) 40 ppm GA_3 applied in a single application; 7) 40 ppm GA_3 applied in a double application (20 ppm at straw color + 20 ppm mid-Stage III); 8) 60 ppm GA_3 applied in a single application; and 9) 60 ppm GA_3 applied in a double application (20 ppm at straw color + 40 ppm mid-Stage III). The first application was made on 30 June. At this timing, GA_3 application is a standard commercial practice; therefore, 20 ppm GA_3 was prepared and applied to the entire orchard through a commercial, air-blast, tractor-mounted sprayer. Scaffold limbs assigned to Treatments 1 and 2 (0 ppm GA_3) were protected with water-resistant bags applied before spraying. Bags were removed by midmorning. Solutions were applied the next morning to all treatments receiving in excess of 20 ppm GA_3 at the first application [i.e., Treatments 4 (10 ppm); 6 (20 ppm); and 8 (40 ppm)]. Treatments receiving a second application were treated on 20 July. Fruit were harvested from limbs on 9 Aug., 1 d before the commercial harvest. Limb yields were normalized based on limb cross-sectional area (LCSA) and expressed as number of fruit/cm^2 of LCSA. In 2011, return bloom was determined on 2010 scaffolds and expressed as the number of reproductive buds per spur and the number of flowers per reproductive bud on the first 25 spurs on 2-year-old wood. The entire experiment was then repeated in 2011 on new scaffolds from different trees. The first application occurred on 20 July and the second on 2Aug. The only treatment differences between 2010 and 2011 were the omission of Treatment 5 and the addition of a 10-ppm GA_3 application in 2011. Pedicel retention force was analyzed in 2011 as a result of a late commercial harvest. Treatments were harvested on 23 Aug. Return bloom of limbs treated in 2011 was determined in 2012 as described previously.

Trial 2 (2010). Secondary and tertiary scaffold limbs of eighth-leaf 'Sweetheart'/Mazzard cherry trees were selected, measured, and replicated in a commercial orchard in Parkdale, OR (lat. 45.53° N, long. 121.61° W) in 2010 as described for Trial 1. Treatments were identical to those of Trial 1. The first treatment application occurred 28 June; the second application of split-application treatments was made on 16 July. Commercial application of GA_3 and protection of treatment limbs receiving rates lower than 20 ppm GA_3 were performed according to the methods outlined for Trial 1. Harvest occurred 1 d before the commercial harvest (13 Aug.). Return bloom was not recorded as a result of severe bacterial canker (*Pseudomonas syringae* pv. syringae) infection that markedly reduced the number of healthy spurs on treatment limbs. A second year (2011) was initiated in a different but similar 'Sweetheart' orchard, comprising identical treatments as provided in the second year of Trial 1, but all selected limbs were sprayed inadvertently as a result of miscommunication with the grower. Consequently, there were no unsprayed limbs (controls) and the results are not reported.

Trial 3 (2010). Whole-tree applications were made to seventh-leaf 'Staccato'/Mazzard cherry trees trained to a modified Spanish bush in a commercial orchard in The Dalles, OR (lat. 45.59° N, long. 121.23° W) in 2010. Forty-eight trees were selected based on canopy uniformity and divided into eight replicates in a RCBD. All treatment trees were contained in a single orchard row blocked by slope: 1) 0 ppm GA_3 (untreated); 2) 0 ppm GA_3 (H_2O + surfactant); 3) 20 ppm GA_3;

4) 30 ppm GA_3; 5) 40 ppm GA_3; and 6) 60 ppm GA_3. All GA_3 treatments were applied in a single day when fruit reached pit hardening (17 June). Harvest occurred 1 d before the commercial harvest (30 Aug.). Return bloom was not determined.

Trial 4 (2012). Scaffold limbs of eighth-leaf 'Sweetheart'/Mazzard cherry trees trained to an open-vase architecture were selected in a commercial orchard in Parkdale, OR (lat. 45.53° N, long. 121.59° W) in 2012. Limb selection was based on basal circumference (measured 10 cm from their attachment to the trunk) as in Trials 1 and 2. Treatments were applied in a single day when fruit reached pit hardening, 6 July: 1) 0 ppm GA_3; 2) 25 ppm GA_3; 3) 50 ppm GA_3; and 4) 100 ppm GA_3. Harvests were performed when the average skin color in the orchard attained a ≈4.0 on the Center tequnique interprofessionel de fruits et légumes, Paris, France (CTIFL) scale (5 Aug., Treatments 1 and 2; 8 Aug., Treatments 3 and 4). A large proportion of treatment limbs was removed from trees during dormancy in 2012 as a result of bacterial canker infection; therefore, return bloom was not evaluated.

Trial 5 (2012). Whole-tree applications were made to 14-year-old 'Lapins'/Mazzard cherry trees trained to a steep leader at the MCAREC, Hood River, OR (lat. 45.68° N, long. 121.52° W) in 2012. Trees were selected based on canopy uniformity and treatments were arranged in a RCBD with four replicates. Treatments were identical to those in Trial 4. A single application was made at pit hardening on 15 June. Harvests were performed when the average skin color in the orchard was ≈5.0 CTIFL (21 July for control; 26 July for Treatments 2 to 4). Return bloom was analyzed spring of 2012 as described in Trial 1.

For all trials, harvested fruit was transported directly to the laboratory where fruit quality attributes were measured: 1) fruit weight was recorded on a digital balance (XP-3000; Denver Instrument, Bohemia, NY); 2) average fruit diameter (at the widest point of the fruit opposite the suture) and fruit firmness were determined nondestructively (Firmtech; Bioworks, Stillwater, OK); 3) skin color was rated on a scale of 1 to 7, where 1 is equivalent to light pink and 7 is dark mahogany, using CTIFL color chips; and 4) soluble solids concentration (SS) was determined using a digital refractometer (Model N1; Atago, Tokyo, Japan) from a composite juice sample prepared with a juicer (Model 6001; Acme Juicer Manufacturing Co., Sierra Madre, CA) fitted with a milk filter (Schwartz Manufacturing Co., Two Rivers, WI). In addition to the attributes described, several additional parameters were evaluated in Trials 4 and 5 to include fruit respiration rate, surface pitting (both induced and baseline levels), fruit weight loss (WL), SB, and titratable acidity (TA). All evaluations were made after 2 and 4 weeks of postharvest storage at 0 °C in commercial zip-lock polyethylene bags (≈1 kg of fruit) with a perforation ratio of ≈2%. For WL, ≈500 g of fruit was packaged in bags, weighed, then placed in cold storage for 4 weeks and re-weighed on removal. Initial and final bag weight was determined with an electronic balance (PC4400; Mettler-Toledo, Zurich, Switzerland). Percent WL was calculated according to the formula, $WL = (W0 - Wf)/W0 \times 100$, where W0 is the initial weight (g) and Wf is the final weight (g). Stem browning was expressed as the percentage of fruit with greater than 30% stem surface discoloration (Clayton et al., 2003). Titratable acidity was determined by titrating 10 mL juice from a composite sample plus 40 mL distilled water to an end point pH of 8.1 using 0.1 N NaOH with a titration system (Model T80/20; Schott-Gerate, Hofheim, Germany) and expressed as percentage of malic acid equivalents.

Respiration rate. Cherry samples of ≈500 g were placed in hermetically sealed glass containers (960 mL) at 20 °C equipped with two rubber sampling ports. After 1 h of incubation, headspace CO_2 concentrations were determined by an O_2/CO_2 analyzer (Model 900161; Bridge Analyzers Inc., Alameda, CA). The analyzer was configured to recirculate headspace gases (i.e., entrance and exit ports of the analyzer were connected to the entrance and exit ports of the glass containers) creating a continuous flow between the glass container and the analyzer. The rate of CO_2 production was calculated as mL $CO_2/kg^{-1} \cdot h^{-1}$.

Natural and induced pitting. Fruit for induced pitting evaluation were immediately stored at 4.5 °C for 4 h before inducing pitting and then stored at 0 °C for 2 weeks before pitting evaluation. Surface pitting was induced by the method of Toivonen et al. (2004) with modification. Briefly, a force was applied to the fruit using an instrument (Toivonen et al., 2004) fabricated to drop a 10-g stainless steel rod 2.5 mm in diameter from a height of 60 mm onto the surface of the fruit. Tip protrusion of the steel rod was adjusted to 1.5 mm from the instrument to provide an adequate force to generate pitting but not excessively so. Thirty to 40 fruit from each replicate were induced, and 25 fruit free of visual skin injury after pit induction were selected for evaluation. After a cold storage period at 0 °C for 2 weeks, subjective and objective analyses of pits were performed according to visual rating and measurement of pit diameter, respectively. Pit diameter data were standardized using a 4-point scale: 1, superficial pitting (pit diameter 1 mm or less, very shallow depression of skin with edges being diffuse); 2, minimal pitting (pit diameter 1 to 2 mm); 3, moderate pitting (pit diameter 2 to 3 mm, deeper and wider with clearly distinct edges); and 4, severe pitting (pit diameter 3 mm or greater, very deep, edges of pits sunken into pulp tissue). An analysis of the natural occurrence of pitting incurred from fruit-to-bucket, fruit-to-fruit, and fruit-to-stem contact during picking, transportation, and sorting was determined on a separate fruit sample and expressed as the percentage of fruit with pit diameters exceeding 3 mm.

Statistical analysis. Statistical analyses were performed using the SAS system software (SAS 9.2; SAS Institute, Cary, NC) and StatSoft Statistica Version 6 (StatSoft, Tulsa, OK). Treatment means were compared using analysis of variance with PROC GLM and significance was tested at $P \leq 0.05$. Mean separation was determined by Fisher's protected least significant difference test. The 0-ppm GA + surfactant treatment was omitted from all statistical analyses to conserve df.

Results

Trial 1. Fruit size of 'Skeena' was not consistently increased by GA_3 in either year (Table 1). Fruit firmness, however, was significantly and markedly improved by low rates of GA_3 in both 2010 and 2011. In 2010, FF increased with rate up to 30 ppm; no further improvements were attained with higher rates. The addition of a low rate concentration (i.e., 10 ppm) in 2011 was sufficient to elicit a significant response in firmness; however, firmness did not continue to increase with rates higher than 10 ppm. Development of skin color was significantly delayed by GA_3, but the highest efficacy was observed at the split-application 30-ppm or single-application 40-ppm rate in 2010 and the 10-ppm rate in 2011. No effects of GA_3 on SS were observed. Split applications did not affect any of the response variables compared with single applications of equivalent rates with the exception of skin color in 2010. Maturity was slightly advanced at the commercial harvest timing in 2011 relative to 2010 as shown by higher SS, lower FF, and darker skin color. Pedicel retention force, evaluated in 2011 as a result of the late harvest timing, was numerically higher for GA_3 treatments but not significantly. Flower bud density and flower number per bud were unaffected by GA_3 rate or timing in either of the subsequent seasons from treatment applications. A greater number of buds per spur and flowers per bud was observed in 2011 relative to 2012.

Trial 2. GA_3 increased 'Sweetheart' cherry fruit size by ≈16% compared with controls (Table 2), but greater improvements in fruit size were not consistently observed at rates higher than 20 ppm. Similarly to fruit size, GA_3 positively affected FF and SS with the lowest rate being the most efficacious. Skin color was numerically, albeit non-significantly, lighter for GA_3 treatments compared with controls. Cropload levels were similar among treatments but were quite low for 'Sweetheart'. Splitting the rate between two application timings, as opposed to one, did not affect fruit quality attributes. Although comparisons with controls could not be made for GA_3 treatments applied in 2011, there were no differences among the GA_3 rates (10 to 60 ppm) and their application timing (single or multiple applications) for all measured attributes (data not shown).

Trial 3. 'Staccato' sweet cherry fruit size was significantly improved (≈12%) from whole-tree applications of GA_3 applied at straw color (Table 3). GA_3 resulted in a ≈42% increase in fruit firmness relative to control fruit. Color was reduced by GA_3

Table 1. Effect of 2010 and 2011 preharvest gibberellic acid (GA_3) treatments on fruit quality attributes of 'Skeena' sweet cherries.

Treatment[z] GA (ppm)	Avg fruit wt (g)	Avg fruit diam (mm)	FF (g·mm^{-1})	SS (%)	Skin color[y] CTIFL	Cropload[x] (no. of fruit/cm^2)	PRF (g)	Return bloom	
								No. of buds/spur	No. of flowers/bud
				2010					
0	11.8 b[w]	30 b	371 c	18.9	5.3 a	7.2 abc	—	3.0	2.7
20	12.7 a	31 a	405 b	19.3	4.8 b	6.0 abc	—	3.7	2.3
30	12.5 ab	31 a	414 ab	19.7	4.7 b	7.3 abc	—	3.0	2.3
30 (20 Stage II, 10 Stage III)	12.2 ab	30.6 ab	440 a	19.1	4.3 c	5.4 c	—	3.6	2.2
40	12.1 ab	30.6 ab	443 a	19.6	4.3 c	5.8 be	—	2.8	2.6
40 (20 Stage II, 20 Stage III)	12.4 ab	30.8 ab	441 a	19.6	4.2 c	9.4 a	—	3.0	2.1
60	12.5 ab	30.8 ab	447 a	19.3	4.2 c	6.3 abc	—	3.0	2.5
60 (20 Stage II, 40 Stage III)	12.5 ab	31.1a	427 ab	19.3	4.3 c	9.3 ab	—	2.7	1.9
				2011					
0	11.7	30.1	316 b	20.7	5.8 a	10.4	180	4.9	3.7
10	12.6	31	370 a	20.9	5.1 b	11.5	210	5.0	3.9
20	12.2	30.7	373 a	20.8	5.1 b	13.6	220	5.0	3.7
30	11.9	30.6	377 a	20.7	4.8 b	12.9	280	4.5	3.8
40	11.9	30.2	390 a	20.4	5.2 b	12	250	4.5	3.8
40 (20 Stage II, 20 Stage III)	12.7	31	383 a	21.5	5 b	10	280	5.3	3.8
60	12.1	30.6	404 a	20.7	4.8 b	13.3	260	4.8	3.7
60 (20 Stage II, 40 Stage III)	11.9	30.5	373 a	20.6	4.9 b	14	220	4.5	4.1

[z]GA_3 was applied as the commercial product ProGibb40%WSG. All GA_3 treatments were applied when fruit were in late Stage II of development (i.e., pit hardening) when skin color transitioned from green to "straw" color. For multiple application treatments, the second application was made ≈2 weeks after the first (fruit were in mid-Stage III development; i.e., cell expansion). Treatments were applied to different trees in 2011.
[y]Skin color was evaluated using CTIFL color chips on a scale of 1 to 7 (light pink to dark mahogany). Fruit from all treatments were harvested on the same date.
[x]Cropload was calculated as the number of fruit/cm^2 of scaffold cross-sectional area. Cross-sectional area was derived from the circumference of the limb, measured at 10 cm from its point of origin to the trunk.
FF = fruit firmness; SS = soluble solids content; PRF = pedicel retention force.
[w]Means were separated within columns by Fisher's protected least significant difference test (LSD) ($P < 0.05$), whereby means associated with different letters are significantly different. Data are means of 12 replicate limbs: n = 50 for fruit weight, fruit diameter, FF, and skin color; n = 1 for SS and cropload.

Table 2. Effect of 2010 preharvest gibberellic acid (GA_3) treatments on fruit quality attributes of 'Sweetheart' sweet cherries.

Treatment[z] GA (ppm)	Avg fruit wt (g)	Avg fruit diam (mm)	FF (g·mm^{-1})	SS (%)	Skin color[y] CTIFL	Cropload[x] (no. of fruit/cm^2)
0	9.4 b[w]	27.4 c	380 b	17.4 b	4.2 a	2.6 ab
20	10.9 a	29.3 b	417 a	18.5 a	3.8 b	2.4 b
30	10.9 a	29.4 b	416 a	18.6 a	4.0 ab	3.8 a
30 (20 Stage II, 10 Stage III)	10.9 a	29.4 b	418 a	18.9 a	3.7 b	2.4 b
40	11.2 a	29.7 ab	419 a	19.1 a	4.0 ab	1.9 b
40 (20 Stage II, 20 Stage III)	10.9 a	29.4 b	414 a	18.8 a	3.7 b	2.3 b
60	11.4 a	29.8 a	417 a	18.4 a	3.8 b	2.0 b
60 (20 Stage II, 40 Stage III)	11.2 a	29.6 ab	417 a	19.1 a	4.0 ab	3.1 ab

[z]GA_3 was applied as the commercial product ProGibb40%WSG to individual scaffold limbs. All GA_3 treatments were applied when fruit were in late Stage II of development (i.e., pit hardening) when skin color transitioned from green to "straw" color. For multiple application treatments, the second application was made ≈2 weeks after the first (fruit were in mid-Stage III development; i.e., cell expansion).
[y]Skin color was evaluated using CTIFL color chips on a scale of 1 to 7 (light pink to dark mahogany). Fruit from all treatments were harvested on the same date.
[x]Cropload was calculated as the number of fruit/cm^2 of scaffold cross-sectional area. Cross-sectional area was derived from the circumference of the limb, measured at 10 cm from its point of origin to the trunk.
[w]Means were separated within columns by Fisher's protected least significant difference test (LSD) ($P < 0.05$), whereby means associated with different letters are significantly different. Data are means of 12 replicate limbs: n = 50 for fruit weight, fruit diameter, FF, and skin color; n = 1 for SS and cropload.
FF = fruit firmness; SS = soluble solids content.

application. The response of these quality attributes apparently saturated at 20 ppm. GA_3 did not significantly alter SS of 'Staccato' fruit. Whole-tree yields differed numerically among treatments as a result of high variability among replicates but were not significantly different.

Trial 4. 'Sweetheart' fruit size was not significantly improved by GA_3 (Table 4). Fruit firmness was significantly increased by 25 ppm GA_3, relative to controls, but greater increases in FF were not detected with increasing GA_3 rate. Fruit firmness increased for all treatment fruit after the 4-week cold storage period. Higher FF associated with GA_3 was maintained throughout the storage period. Three additional days were required for 50- and 100-ppm-treated fruit to attain an equivalent skin color as control and 25 ppm GA_3 fruit (4.0 CTIFL); however, assessment of skin color under laboratory lighting indicated that 100 ppm cherries were slightly darker. Soluble solids concentration of GA_3-treated fruit were higher, albeit nonsignificantly. Respiration rate, ethylene evolution (data not shown), and weight loss were unaffected by GA_3 rate at harvest or after 4 weeks of cold storage. GA_3 resulted in a slight reduction in SB, but significant differences were only detected at 25 ppm compared with the control. Stem browning was reduced by 27% and 40% for 25 ppm GA_3 fruit after 2 and 4 weeks of storage compared with controls, respectively. Pitting susceptibility of 'Sweetheart' fruit was improved by GA_3 treatments as determined by pit induction (Fig. 1); these results were further supported by natural pitting data. In both pitting experiments, positive benefits of GA_3 were optimized at 25 ppm.

Trial 5. There were no differences among treatments in fruit size, SS, respiration rate (Table 5), or ethylene evolution (data not shown) at harvest or after 4 weeks of cold storage for 'Lapins' cherries. Fruit firmness was significantly higher for GA_3-treated fruit relative to controls. Fruit firmness appeared to saturate at 25 ppm; rates as high as 100 ppm had no additional effects. Titratable acidity of fruit for all GA_3 treatments was significantly lower than control fruit at harvest but not after cold storage. GA_3 delayed harvest by 5 d, but rate did not affect color development. GA_3 did not influence postharvest WL. Despite generally lower SB for GA_3 treatment fruit, only the 25-ppm rate had significantly less SB than controls. Stem browning increased with storage duration, irrespective of treatment; however, compared with controls, 25 ppm GA_3 reduced SB by 45% and 40% after 2 and 4 weeks of storage, respectively. GA_3-treated fruits of 'Lapins' pitted significantly less than control fruits after pit induction (Fig. 1). Natural pitting was also observed to be reduced for GA_3 treatments as compared with controls. Pitting, however, did not follow a rate response to GA_3. Return bloom was significantly affected by GA_3. This was attributed to fewer flowers per reproductive bud

(i.e., 79% and 38% of controls for 50- and 100-ppm GA_3 treatments, respectively; Table 5). A numerical reduction in reproductive buds per spur was only evident at 100 ppm GA_3, although not significantly (P = 0.11).

Table 3. Effect of 2010 preharvest gibberellic acid (GA_3) treatments on fruit quality attributes of 'Staccato' sweet cherries.

Treatment[z] GA (ppm)	Avg fruit wt (g)	Avg fruit diam (mm)	FF (g·mm^{-1})	SS (%)	Skin color[y] CTIFL	Avg tree yield (kg/tree)
0	8.6 b[x]	26 c	320 b	24.1 a	4.8 a	58.0
20	9.6 a	27 b	459 a	23.6 ab	4.1 ab	48.7
30	9.8 a	27.8 a	448 a	24 a	3.9 b	67.5
40	9.5 a	27.3 ab	474 a	22.9 ab	3.6 b	63.5
60	9.7 a	27.2 ab	440 a	22.1 b	4 b	81.6

[z]GA_3 was applied as the commercial product ProGibb40%WSG to whole canopies. All GA_3 treatments were applied when fruit were in late Stage II of development (i.e., pit hardening) when skin color transitioned from green to "straw" color.
[y]Skin color was evaluated using CTIFL color chips on a scale of 1 to 7 (light pink to dark mahogany). Fruit from all treatments were harvested on the same date.
[x]Means were separated within columns by Fisher's protected least significant difference test (LSD) (P < 0.05), whereby means associated with different letters are significantly different. Data are means of eight replicate trees: n = 50 for fruit weight, fruit diameter, FF, and skin color; n = 1 for SS and yield.
FF = fruit firmness; SS = soluble solids content.

Discussion

Fruit quality at harvest. Fruit firmness is an essential attribute affecting the quality of sweet cherries after postharvest storage and shipping. Consumer preference for sweet cherries was positively related to FF (Dever et al., 1996; Guyer et al., 1993; Kappel et al., 1996). In fact, both trained and untrained consumer panels were capable of distinguishing different firmness classes of cherries classified analytically by a Firmtech (Ross et al., 2009), affirming that data generated by this instrument are useful for estimating consumer perception of cherry texture. In their work, a minimum of 40 g·mm^{-1} was required for consumers to distinguish gradations of firmness, which was roughly equivalent to the increase in firmness attributed to GA_3 for all of the cultivars evaluated in the present study. In fact, FF was the most consistent response variable affected by GA_3,

Table 4. Effect of 2012 preharvest gibberellic acid (GA_3) treatments on average fruit size (fruit weight and diameter), yield, fruit quality attributes (flesh firmness, soluble solids concentration, titratable acidity, skin color), and respiration rate of 'Sweetheart' sweet cherries at harvest and fruit quality attributes, respiration rate, stem browning, and fruit weight loss after 4 weeks of postharvest storage at 0 °C.

	Harvest								Post-harvest						
Treatment[z] GA (ppm)	Avg fruit wt (g)	Avg fruit diam (mm)	FF (g·mm^{-1})	SS (%)	TA (%)	Skin color[y] CTIFL	Cropload[x] (no. of fruit/cm^2)	Resp. rate (mL CO_2/ kg^{-1}·h^{-1})	FF (g·mm^{-1})	SS (%)	TA (%)	Skin color CTIFL	Resp. rate (mL CO_2/ kg^{-1}·h^{-1})	Stem browning (%)	Wt loss (%)
0	9.5	27.1	298 b[w]	19.3	0.89	4.0 a	32.8	15.2 b	319 b	20	0.78	5.0	16.5	39 a	5.3
25	10.1	27.8	331 a	20.8	0.95	4.0 a	39.2	16.9 b	361 a	20.9	0.82	5.0	15.5	24 b	5.1
50	10.8	27.6	345 a	22.5	0.91	4.1 a	28.4	16.3 b	359 a	21.6	0.80	5.0	16.0	28 ab	4.9
100	10.2	28.1	352 a	21.2	0.92	4.5 b	23.7	17.8 a	368 a	20.8	0.81	5.5	15.8	26 ab	5.3

[z]GA_3 was applied as the commercial product ProGibb40%WSG. All GA_3 treatments were applied when fruit were in late Stage II of development (i.e., pit hardening) when skin color transitioned from green to "straw" color.
[y]Skin color was evaluated using CTIFL color chips on a scale of 1 to 7 (light pink to dark mahogany). Fruit were harvested when skin color achieved a predefined harvest value (≈4.0). 0 and 25 ppm GA_3 treatments were harvested on 5 Aug.; 50 and 100 ppm GA_3 required 3 additional d to achieve an equivalent value.
[x]Cropload was calculated as the number of fruit/cm^2 of scaffold cross-sectional area. Cross-sectional area was derived from the circumference of the limb, measured at 10 cm from its point of origin to the trunk.
FF = fruit firmness; SS = soluble solids concentration; TA = titratable acidity.
[w]Means were separated within columns by Fisher's protected least significant difference test (LSD) (P < 0.05), whereby means associated with different letters are significantly different. Data are means of 4 replicate limbs: n = 100 for fruit weight, fruit diameter, and FF; n = 25 for respiration rate; n = 50 for skin color; n = 1 composite sample (25 fruit) for TA and SS; n = 25 for MS; n = 50 for SB.

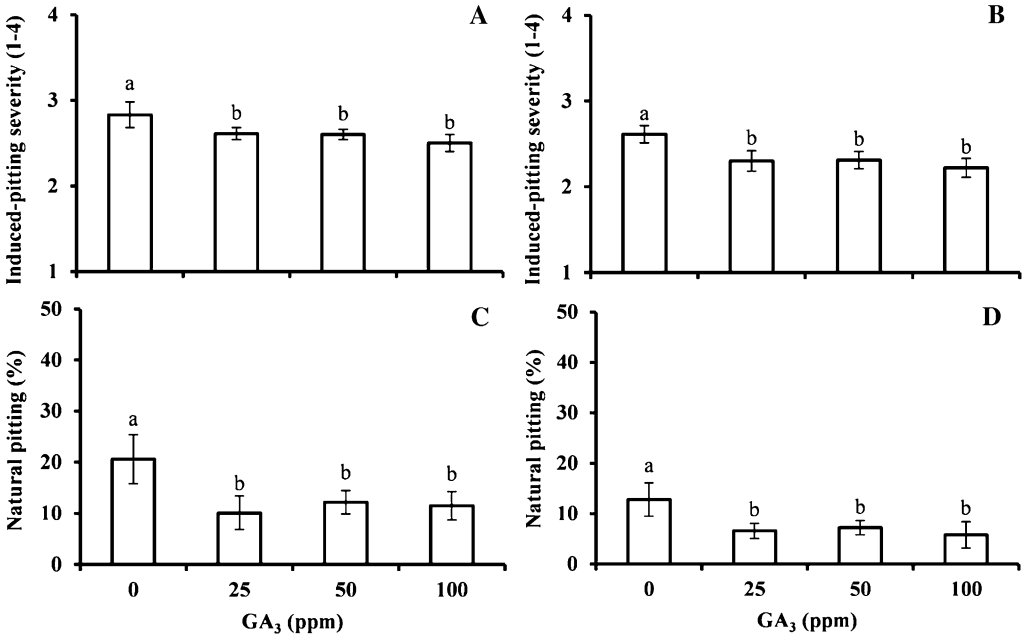

Fig. 1. Effect of preharvest gibberellic acid (GA_3) treatments on induced pitting severity and natural pitting incidence of 'Lapins' (**A, C**) and 'Sweetheart' (**B, D**) cherries after 2 weeks of storage at 0 °C. Vertical bars represent SD. Means were separated between treatments by Fisher's protected least significant difference test (LSD) (P < 0.05), whereby means associated with different letters are significantly different.

Table 5. Effect of 2012 preharvest gibberellic acid (GA_3) treatments on average fruit size (fruit weight and diameter), yield, fruit quality attributes (flesh firmness, soluble solids concentration, titratable acidity, skin color), and respiration rate of 'Lapins' sweet cherries at harvest and fruit quality attributes, respiration rate, stem browning, and fruit weight loss after 4 weeks of postharvest storage at 0 °C.

	Harvest							Post-harvest							Return bloom	
Treatment[z] GA (ppm)	Avg fruit wt (g)	Avg fruit diam (mm)	FF ($g \cdot mm^{-1}$)	SS (%)	TA (%)	Skin color[y] CTIFL	Yield (kg)	Resp. rate (mL CO_2/ $kg^{-1} \cdot h^{-1}$)	FF ($g \cdot mm^{-1}$)	SS (%)	TA (%)	Skin color CTIFL	Resp. rate (mL CO_2/ $kg^{-1} \cdot h^{-1}$)	Stem browning (%)	Wt loss (%)	Buds/spur (no.)	Flowers/bud (no.)
0	12.2	30.7	231 b[x]	17.9	0.81 a	4.9	45.4	23.2	258 b	18.1	0.65	6.0	26.5	25 a	4.8	3.5	2.9 a
25	12.1	30.7	268 a	17.9	0.74 b	5.2	57.1	25.1	291 a	17.8	0.62	6.0	25.0	15 b	4.9	3.7	2.8 ab
50	11.4	30.0	278 a	17.0	0.74 b	4.9	72.4	24.6	317 a	18.0	0.60	6.0	24.3	16 ab	4.8	3.4	2.3 b
100	11	29.6	267 a	16.7	0.74 b	4.9	57.9	25.1	311 a	17.8	0.63	6.0	24.3	20 ab	4.7	2.5	1.1 c

[z]GA_3 was applied as the commercial product ProGibb40%WSG. All GA_3 treatments were applied when fruit were in late Stage II of development (i.e., pit hardening) when skin color transitioned from green to "straw" color.
[y]Skin color was evaluated using CTIFL color chips on a scale of 1 to 7 (light pink to dark mahogany). Fruit were harvested 21 July when skin color achieved a predefined harvest value (≈5.0). Treatments of 25, 50, and 100 ppm GA_3 required 5 additional d to achieve an equivalent value to 0 ppm.
[x]Means were separated within columns by Fisher's protected least significant difference test (LSD) ($P < 0.05$), whereby means associated with different letters are significantly different. Data are means of four replicate trees: n = 100 for fruit weight, fruit diameter, and FF; n = 25 for ethylene detection and respiration rate; n = 50 for skin color; n = 1 composite sample (25 fruit) for TA and SS; n = 25 for weight loss; n = 50 SB.
FF = fruit firmness; SS = soluble solids concentration; TA = titratable acidity; SB = stem browning.

irrespective of cultivar or application method (i.e., scaffold limbs or whole trees). Scaffold limb applications provided an acceptable research model to investigate GA_3 activity as a result of limited translocation of GA_3 within tissues and limbs of cherry trees (Elfving and Visser, 2005), especially during periods of high fruit sink strength (Cristoferi and Filiti, 1983).

Firmness of late-maturing cultivars consistently responded to fairly low rates (i.e., 10 to 25 ppm) of GA_3 as previously documented for earlier-maturing cultivars (Basak et al., 1998; Clayton et al., 2003; Facteau, 1982a; Facteau and Rowe, 1979; Facteau et al., 1985a, 1985b; Looney and Lidster, 1980) as well as 'Lapins' and 'Sweetheart' (Choi et al., 2002; Horvitz et al., 2003; Kappel and MacDonald, 2002, 2007). We are unaware of any studies relating GA_3 to fruit quality of the late-season ripening cultivars Staccato and Skeena, the latter of which comprises considerable acreage in Oregon and Washington. Irrespective of genotypic differences, FF was not further improved by our higher treatment rates of GA_3, a result consistent with reports for 'Bing' and 'Sweetheart' (Facteau et al., 1985a; Horvitz et al., 2003; Kappel and MacDonald, 2002).

An oversupply of cherries during the midseason harvest window has compelled producers to expand acreage of late-maturing cultivars. The potential use of GA_3 to further delay harvest is an attractive horticultural strategy. Low rates of GA_3 (10, 20, or 25 ppm depending on the experiment) typically reduced color relative to control fruit (Trials 1 to 3); higher rates, however, did not further affect color at harvest with the exception of 'Skeena' in 2010 in which 30 ppm produced significantly lighter fruit than 20 ppm. Interestingly, despite inhibiting color development, GA_3 did not have an apparent effect at harvest on pedicel retention force of 'Skeena' cherries in 2011, indicating that these two senescence-associated processes are differentially controlled. We did not determine the rate of color development in Trials 1 to 3, but when provided additional days to darken to control levels, 25, 50, and 100 ppm GA_3-treated 'Lapins' did not differ in their time requirements. These results agree with those for 'Bing' (Facteau et al., 1985a); however, in other experiments, 'Bing' and 'Lambert' were delayed 2, 5.1, and 6.4 d from 20, 50, and 100 ppm GA_3, respectively (Facteau et al., 1985a). 'Sweetheart' treated with 50 and 100 ppm GA_3 required 3 additional d to reach the color of control and 25 ppm cherries, which simultaneously attained a CTIFL rating of 4.0. It is unclear why 'Sweetheart' required a higher rate of GA_3 to inhibit color relative to 'Lapins', although in our climate, 'Sweetheart' produces a much lighter cherry than most commercially produced cultivars, including 'Lapins' (Long, 2007).

Fruit size response to GA_3 was inconsistent for the cultivars evaluated. GA_3 had a direct, significant effect on fruit size of 'Staccato' and 'Sweetheart' (the latter in Trial 2 only) relative to control fruit. For 'Skeena', however, fruit size was affected in only 1 of 2 years. Unresponsive fruit growth of 'Lapins' and 'Sweetheart' (Trial 4 only) to GA_3, despite requiring additional days to darken, does not agree with previous findings for these cultivars in Canada (Choi et al., 2002; Kappel and MacDonald, 2002, 2007) or Argentina (Horvitz et al., 2003). There are several examples of inconsistent or poor response of cherry fruit size to GA (Facteau et al., 1985a; Clayton et al., 2003; Looney and Lidster, 1980). One possible explanation for the disparity in size response between the two 'Sweetheart' trials may be attributed to marked differences in fruit density between years; croploads in the "unresponsive" 'Sweetheart' were nearly 10-fold those of Trial 2.

Multiple applications of GA_3 did not improve fruit quality attributes when the same rate was applied in a single application, as previously shown for 'Bing' and 'Lambert' (Facteau et al., 1985a), and 'Sweetheart' (Kappel and MacDonald, 2002). Interestingly, Kappel and MacDonald (2007) observed very little difference among timings of GA_3 applications ranging from 10 d before straw color to 1 week after straw color on 'Sweetheart' fruit quality. Moreover, Zhang and Whiting (2011a) observed increased fruit size at harvest from various isomers of GA (including GA_3) applied 8 d after full bloom. Collectively these results suggest developmental insensitivity of cherry fruit to GA_3.

Return bloom. In addition to affecting fruit quality, GA_3 strongly inhibits floral induction (Oliveira and Browning, 1993). At low rates, GA_3 did not reduce return bloom of 'Skeena' or 'Lapins'. At high concentrations, however, GA_3 significantly inhibited return bloom of 'Lapins', as previously documented for 'Bing' (Facteau et al., 1989; Lenahan et al., 2006; Proebsting and Mills, 1974). Lenahan et al. (2006) concluded that GA_3 and $GA_{4/7}$ were ineffective at producing balanced croploads of 'Bing' the subsequent season; $GA_{4/7}$ having a greater effect than GA_3. We hypothesized that high rates of GA_3 may improve crop value for 'Sweetheart' and 'Lapins' given these genotypes' inherently high productivity, a trait that promotes "oversetting," particularly for 'Sweetheart' (Einhorn et al., 2011). In our study, lower return bloom was attributed to fewer flowers per floral bud and not the result of a reduction in the number of reproductive buds per spur, as similarly observed for 'Bing' (Facteau et al., 1989; Lenahan et al., 2006). Interestingly, return bloom in 2013 was significantly delayed 2, 6, and 9 d for 25, 50, and 100 ppm GA_3, respectively. Lenahan et al. (2006) also observed flowering delays from GA treatments; however, in their study, the delay in bloom was only apparent for the 200-ppm GA treatments. Although the potential to moderate cropload is compelling, in our case, the negative consequences on yield from the reductions observed in 'Lapins' return bloom, even at 50 ppm GA_3, would likely be too severe (Lenahan et al., 2006). Poor predictability of GA_3 rate on floral induction challenges the use of GA_3 as a cropload management tool.

Unfortunately, 'Sweetheart' trees suffered high mortality as a result of bacterial canker infection on selected limbs, eliminating a statistically valid evaluation of return bloom.

Postharvest fruit quality. Respiration rate, ethylene evolution, and WL of 'Lapins' and 'Sweetheart' were unaffected by GA_3. Stem browning, a major arrival issue of sweet cherry transported over long distances (Shick and Toivonen, 2000), was reduced by 25 ppm GA_3 after cold storage as previously shown (Horvitz et al., 2003; Koyuncu et al., 2008; Özkaya et al., 2006). Higher rates, however, did not improve the response. 'Bing' cherries treated with GA_3 plus Prohexadione-Ca (P-Ca) had a significantly higher percentage of green, turgid pedicels compared with those treated with P-Ca alone or untreated after 30 d cold storage (Zhang and Whiting, 2011b). The role of GA in maintaining pedicels is not clear, although not all researchers have observed lower SB from GA_3 treatments (Clayton et al., 2003).

A positive relationship between FF and pitting resistance of sweet cherry has been previously documented (Facteau, 1982a, 1982b; Toivonen et al., 2004). Firm cherries resisted impact and compression pressures better than soft cherries (Facteau, 1982b). Moreover, GA_3 reduced the sensitivity of 'Buttner's Red' cherry to bruising damage proportional to rate from 10 to 20 ppm (Basak et al., 1998). Similarly, GA_3 at 15 ppm reduced surface pitting of 'Van' subjected to postharvest bruising but not 'Lambert' (Looney and Lidster, 1980). In our trials, GA_3 rate (in excess of 25 ppm) did not affect pitting, a reasonable result given that higher rates did not increase FF. 'Lambert' and 'Bing' cherries had reduced surface pitting from applications of GA_3 at 10 ppm (Facteau, 1982b; Facteau and Rowe, 1979). Recent experiments designed to manipulate preharvest factors to produce a wide range of pitting for 'Sweetheart' and 'Lapins' yielded a strong, positive relationship between FF and pitting (Wang and Einhorn, unpublished data).

Despite the influence of GA_3 on FF and the fairly strong negative correlation between pitting and cherry firmness, pitting appears to be quite complex and is likely regulated by multiple factors (Facteau et al., 1985b; Looney and Lidster, 1980; Toivonen et al., 2004). The fact that GA_3 did not affect 'Lapins' or 'Sweetheart' SS or fruit size at harvest, or alter respiration rate and WL during storage, implies that factors associated with the increase in FF contribute to pitting resistance. The relationships between cell wall hydrolytic enzyme activity (Andrews and Li, 1995; Choi et al., 1995), pectic substances, and alcohol insoluble solids (Facteau, 1982a, 1982b; Looney and Lidster, 1980) and FF in sweet cherries have been characterized but have not been consistently influenced by GA_3. Notably, FF alone is not a strong predictor of pitting, because fruits of 'Sweetheart' produced in the United States and Chile tend to have the least resistance to pitting but the highest FF among cultivars produced (J.P. Zoffoli, personal communication; Long, 2007). Anecdotal evidence suggests a strong genetic disposition for pitting. Under our environmental conditions 'Van', 'Sweetheart', and 'Lapins' are distinguishable from other cultivars based on their exceptionally high propensity for pitting, the latter two cultivars originating from crosses with 'Van' (Lane and MacDonald, 1996; Lane and Schmid, 1984). Interestingly, an analysis of pitting resistance of nine sweet cherry cultivars in Canada found 'Sweetheart' and 'Lapins' to possess the greatest resistance to pitting (Kappel et al., 2006). Clearly there is an interaction between genotype and environment. A comparative genetics/genomics research approach to understanding sweet cherry surface pitting using genotypes with distinct levels of pitting might provide useful insights into the disorder and potentially inform future breeding efforts.

Conclusion

One of our primary objectives was to determine whether moderate rates of GA_3 (between 25 and 60 ppm) might augment fruit quality attributes for late-maturing cultivars produced in the PNW. GA_3 efficacy was highest at 10 to 25 ppm on the following fruit quality attributes: FF, SS, TA, SB, and surface pitting. High rates, on the contrary ($\approx$100 ppm GA), affected floral bud induction and, potentially, color delay; however, the severe reduction in return bloom would have had an adverse impact on subsequent season yield. Further evaluation of high GA_3 rates to regulate 'Sweetheart' croploads is warranted. Splitting applications between pit hardening and fruit expansive growth stages did not enhance harvest delay or improve any of the attributes analyzed; however, it is plausible that the 20 ppm provided during the first application timing was sufficient to elicit the response of individual attributes. We did not evaluate the role of single applications made after straw color, but this approach would be valuable to provide producers with a broader window for GA_3 application, thus avoiding applications near rain events that are associated with higher cracking sensitivity of fruit (Kappel and MacDonald, 2007). At low rates, GA_3 positively affected FF, the only response variable consistently altered. We conclude that genotypic differences among cherry cultivars do not appear to interact strongly with, or affect fruit response to, GA_3.

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