Effect of gibberellic acid on fruit cracking and quality of Bing and Sam sweet cherries

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Cline, J. A. and Trought, M. 2007. **Effect of gibberellic acid on fruit cracking and quality of Bing and Sam sweet cherries**. Can. J. Plant Sci. **87**: 545–550. Rain-induced cracking of sweet cherries (*Prunus avium* L.) is a major problem in many cherry growing regions throughout the world. One method to reduce cracking is to grow cracking resistant cultivars; however, no completely effective control measures are currently available to eliminate this problem. Studies conducted in New Zealand to test the ameliorating properties of gibberellic acid sprays to reduce cracking were examined. The results revealed that repeated or singular foliar applications at 10 or 40 mg L^{-1} gibberellic acid (GA_3), respectively, increased both fruit cracking, and fruit firmness, but delayed fruit colour development.

Key words: *Prunus avium*, cherry splitting, cracking

Cline, J. A. et Trought, M. **Effet de l'acide gibberelique (AG_3) sur le fendillement du fruit et la qualité des cerises douces Bing et Sam**. Can. J. Plant Sci. **87**: 545–550. Le fendillement des cerises douces (*Prunus avium* L.) attribuable à l'eau de pluie pose un grave problème dans les régions du monde où l'on cultive ce fruit. Une façon de l'atténuer consiste à cultiver des variétés résistantes. Malheureusement, il n'existe présentement aucune méthode totalement efficace pour mettre fin à ce problème. Des études entreprises en Nouvelle-Zélande ont permis de tester les propriétés bénéfiques des pulvérisations d'acide gibberelique dans cette optique. Les résultats indiquent que des applications répétées ou une seule application foliaire de 10 ou de 40 mg d'AG_3 par litre, augmentent respectivement le fendillement et la fermeté des fruits tout en retardant la coloration de ces derniers.

Mots clés: *Prunus avium*, fendillement des cerises, craquelures

Rain at harvest in many cherry production regions of the world is a serious problem and risk associated with fruit cracking and crop loss (Trought 1986). Gibberellic acid (GA_3) sprays have been evaluated in many cherry growing regions to reduce the risk of crop loss by making fruit more resistant to cracking. Gibberellic acid is used widely in other horticultural crops for improving fruit set and also to control apple russeting (Taylor and Knight 1986) and cracking of pomegranate fruit (Sepahi 1986) and litchi (Sharma and Dhillon 1986) and to inhibit flowering of *Prunus* species (Coneva and Cline 2006; Lenahan et al. 2006). Sprays of GA_3 have been widely adopted in commercial orchards because they have consistently been shown to increase fruit size and firmness of cherry (Proebsting et al. 1973; Facteau 1984; Facteau et al. 1985a, b; Looney 1985; Facteau 1986; Sive and Resnizky 1988; Kupferman 1989; Choi et al. 2002; Kappel and MacDonald 2002; Horvitz et al. 2003; Clayton et al. 2006; Özkaya et al. 2006). However, evidence that GA_3 can reduce rain induced fruit cracking is contradictory.

This experiment was designed to determine the effect of pre-harvest foliar applications of GA_3 on the cracking and quality of two sweet cherry cultivars that differ in their susceptibility to rain-induced cracking. A second objective was to test the timing of application and concentration of GA_3 sprays to determine the relative benefits of single or repeated applications.

MATERIALS AND METHODS

This trial was conducted in a commercial orchard in Blenheim, New Zealand. The planting site had trees planted within 1-m herbicide strips, with a north–south orientation, consisting of two alternating rows of 8-yr-old *Prunus avium* cv. Bing and *Prunus avium* cv. Sam, both on Mazzard (*Prunus avium* F.12/1) rootstock. Cultivars Sam and Bing were selected for their lower and greater susceptibility to cracking, respectively (Christensen 1972a). Trees, which were treated with 2 mL of paclobutrazol per tree in 1989, were trained to a Lincoln Trellis ("T" trellis) at a height of approximately 2 m above the ground, had well-established tree canopies, and were cropping heavily and consistently. No fertilizers were applied to the trees since planting, and irrigation was applied using a travelling gun as necessary. No irrigation was applied during the season under study.

The experimental layout consisted of a single factorial randomised complete block design with cultivars analysed

Abbreviations: GA_3, gibberellic acid

Table 1. Summary of gibblerellic acid sprays applied to *Prunus avium* Sam and Bing trees

Treatment description	GA_3 concentration (ppm)	Surfactant concentration (% vol/vol)	Number of spray applications	Date(s) of application			
Untreated control	0	0	–	–	–	–	–
Water only	0	0.025	4	Nov. 17	Nov. 26	Dec. 06	Dec. 08
Repeated GA	10	0.025	4	Nov. 17	Nov. 26	Dec. 06	Dec. 08
Single GA	40	0.025	1	–	–	–	Dec. 08

separately due to their different harvest dates. Twenty trees of each cultivar, with a "border" tree between each treated tree to avoid spray drift, were selected and each tree was divided into half-tree experimental plots, one on the east and one on the west side of the Lincoln trellis. Each randomly selected experimental plot was treated with one of two gibberellic acid (Grocel GA_3 liquid, ICI, New Zealand) sprays, or a water only spray. One plot was left untreated. Sprays consisted of: (1) untreated control; (2) four sprays of water and surfactant (Cittowet, BASF) only; (3) four sprays of 10 mg L^{-1} GA_3; and (4) 1 spray of 40 mg L^{-1} GA_3 (Table 1). The total amount of GA_3 applied in treatments (3) and (4) was similar, and differed only in the concentration and number of applications made. All sprays were applied at the straw-yellow stage of development to runoff, completed in the morning between 0800 and 1000, and only applied on days with little or now wind. A tarp was erected to prevent spray drift onto neighbouring experiment units.

Harvest Measurements

On Dec. 17 and 27, fruit from all of the Sam and Bing trees, respectively, were harvested and transported to the laboratory for cracking and fruit quality analyses. The number of cracked fruit was estimated by counts from a representative sample of approximately 150 fruit and classified according to four colours based on colour comparators (Okanagan Federated Shippers, Kelowna, BC): <3 (yellow–pink), 3 (pink), 33 (red), and 34 (dark red). Since a high level of rain-induced cracking of Bing occurred at harvest, there was concern that a representative sample of sound fruit for further fruit quality analyses might not be obtained. A sampling error, introduced by the inadvertent selection of fruit inherently resistant to cracking, could have confounded the treatment effects. It was decided, therefore, that detailed and objective measurements of the quality of Bing fruit was not possible. For the cultivar Sam, a random subsample of 10 remaining sound fruit was randomly selected for fruit quality assessment. Individual measurements of fruit weight, size, colour, firmness, and soluble solids were recorded for each fruit. Fruit were weighed to the nearest milligram and the size of fruit was measured in three dimensions using digital callipers. The longitudinal, suture, and lateral diameter of the fruit, referred to below, correspond with the vertical distance between the pedicel cavity and stylar scar, the maximum horizontal diameter at the suture scar, and the maximum horizontal diameter perpendicular to the suture scar, respectively.

Fruit soluble solids were measured using an Atago PR-100 (Japan) temperature-compensating digital refractometer by making a 5–10 mm deep horizontal incision at the position of maximum fruit diameter using a scalpel. Approximately 0.5 mL of juice was expressed directly onto the surface of the refractometer and the measurement immediately taken.

Fruit firmness was measured using a type 00 Durometer (2.83 mm spherical indentor, maximum load 113 g, Shore Instruments and Manufacturing Co., Jamaica, NY). Two replicate measurements of firmness were recorded on the opposite cheek sides of the fruit, at a position located at the fruit's maximum width, perpendicular to the suture scar.

Fruit colour was quantified using a Minolta Chroma Meter CR-100 (Ramsey, NJ) by measuring the colour on two opposite sides of the fruit cheek, perpendicular to the suture scar. Values are expressed using the CIE L^*a^*b system where L^* is the lightness factor ranging from black ($-L^*$) to white ($+L^*$), the a^* is a chromaticity coordinate ranging from green ($-a^*$) to red($+a^*$) and, b^* is the chromaticity coordinate ranging from blue ($-b^*$) to yellow ($+b^*$).

Fruit Moisture Content and Evapotranspiration Rates

Five Sam fruit from each treatment replicate, representative of the average fruit size and maturity, were selected on Dec. 18 and immediately transported to the laboratory. Fruit pedicels were excised leaving a 1- to 2-mm stub attached. Fruit were immediately weighed and placed into individual impressions (2.5 cm diameter, 10 mm deep) within a styrofoam tray and placed into a 20°C constant temperature environment with a small circulating fan, but without lighting. After approximately 24 h, fruit were reweighed and the change in weight was recorded. Fruit moisture content was subsequently determined by oven drying at 100°C to a constant weight.

Statistical Analyses

Analyses of variance of fruit weight, size, firmness, colour, soluble solids, fruit evapotranspiration rates and moisture content, and cracking percentages were calculated for each cultivar separately. Cracking percentage data were transformed using the arc sin function; however, since no improvement in partitioning the variance was achieved, data are displayed as their original untransformed values.

RESULTS

Seasonal Weather Conditions

The persistence of inclement weather in New Zealand from bloom until harvest resulted in one of the poorest and wettest cherry seasons on record. Not only were crop loads light due to poor pollination and fruit set at bloom, but many of the remaining fruit succumbed to extensive rain-induced fruit cracking at harvest. From full bloom dates of Oct. 07 and 12 for Bing and Sam, respectively, up to harvest the accumulated degree days (base 5°C) were 697 and 566 (data not shown). Total rainfall in December alone amounted to 71 mm, with rain occurring on 17 of the 31 d; this was well above the seasonal average. Due to the unseasonably cool temperatures, harvest was delayed by approximately 10 d compared with an average season.

Fruit Cracking

GA_3 sprays had a marked adverse effect on the cracking of Bing fruit, but had a non-significant effect on the cultivar Sam (Table 2). Single and repeated sprays of GA_3 increased cracking of Bing fruit from 17 to 27% in comparison with untreated control fruit. Sprays of water had no effect on cracking. Due to persistent rain during harvest, cracking on the trees of untreated fruit reached 51% for Bing and 45% for Sam. Although GA_3 sprays tended to increase the cracking of Sam fruit by 9 to 17% compared with untreated control fruit, this effect failed to be significant.

The marketable yield of export quality Bing fruit, which included all fruit with cracks less than 2 mm in length, was reduced by single and repeated GA_3. Marketable yields of fruit from single and repeated spray treatments were reduced to 26 and 35% of total fruit, compared with 56% for untreated control fruit. Marketable yields of Sam fruit, nearly 10% greater than Bing, followed the same trend, even though treatment effects were not significant.

For the cultivar Bing, the distribution of sizes of fruit cracks were influenced by GA_3 sprays. Although both GA_3 treatments reduced the number of cracks <2 mm and 2–4 mm in size, there was a very marked increase in the percentage of fruits with cracks >4 mm. Crack size distribution of Sam fruit was only different in the >4 mm size category; both GA_3 treatments had a significantly greater proportion of fruit with >4 mm cracks, whereas no treatment differences in the number of <2 mm and 2–4 mm cracks were observed.

Fruit Quality

A single application of 40 mg L^{-1} GA_3 made at the beginning of stage III of fruit development, when fruit were straw yellow in colour, increased fruit weight by 7% compared with untreated control fruit (Table 3). Although the repeated GA_3 treatments of 10 mg L^{-1} tended to increase fruit weight, this effect was not significant. Fruit soluble solid levels from GA_3-treated fruit were unaffected by treatment. The effect of GA_3 sprays on fruit moisture content was inconsistent. Repeated sprays of 10 mg L^{-1} GA_3 slightly increased the moisture content of Sam fruit above that of the untreated control fruit, whereas a single application of 40 mg L^{-1} GA_3 had no effect on fruit moisture content. Applications of water alone increased fruit moisture content in comparison with untreated control fruit, but these were not different from GA_3 treated fruit. GA_3 sprays had no effect on fruit evapotranspiration (data not shown).

The increase in fruit weight following single applications of GA_3 was associated with greater longitudinal, suture, and lateral fruit diameters in comparison with untreated control fruit. Repeated applications of GA_3 increased the lateral diameter of the fruit, but had no effect on fruit longitudinal and suture diameters. Both GA_3 treatments increased fruit firmness by 5% compared with untreated control fruit (Table 3).

Applications of GA_3 made to both the cultivars Bing and Sam delayed fruit colour development (Table 4). There was no difference in the colour development of fruit from untreated and water only treatments. At the harvest of untreated Bing fruit, a greater percentage of fruit treated with GA_3 was observed to be in the <3 colour classification, and a smaller proportion of fruit in the 33 and 34 colour classification, whereas no difference existed in the percentage of fruit in the colour 3 classification. The same trend was observed for GA_3 treated fruit from 'Sam trees, although compared with Bing, a greater percentage of untreated control fruit were darker in colour. Compared with Bing at harvest, GA_3-treated Sam fruit had a greater number of fruit in the 3 and less fruit in the 34 colour classifications (Table 4)

DISCUSSION AND CONCLUSION

This investigation describes the effects that preharvest foliar applications of GA_3 have on two sweet cherry cultivars that are reported to differ in their cracking susceptibility (Christensen 1972a). The cultivar Bing, considered the more susceptible to cracking, showed greater levels of cracking when sprayed with GA_3 in comparison with the less susceptible cultivar, Sam, but both were markedly influenced by GA_3 sprays. Single applications of 40 mg L^{-1} GA_3 did not influence fruit cracking, fruit quality, or colour development in comparison with repeated applications of 10 mg L^{-1} GA_3.

Our observation that GA_3 sprays increased fruit cracking of Bing contradicts the finding of Looney (1985), Dawood (1986), Facteau (1986), Barsy et al. (1988), and Kupferman (1989), Usenik et al. (2005), who found GA_3 to reduce cracking. However, our results are confirmed by others who found GA_3 sprays increased cracking (Proebsting et al. 1973; Rasmussen and Grauslund 1983). In a previous New Zealand study, the application of GA_3 sprays on the cultivars Merton Premier, Bing, and Dawson indicated that GA_3 delayed harvest, increased fruit firmness, weight, and soluble solids, but had no influence on fruit cracking (Facteau 1984; Horvitz et al. 2003). Balasubramaniam and Agnew (personal communication) found that GA_3 applied at the beginning of stage three of fruit growth significantly improved post harvest handling, storage quality, and reduced fruit pitting in New Zealand. The effect of GA_3 was greatest in Bing, followed by Rainier, Stella, and Dawson, with a rate of 10 mg L^{-1} GA_3 having a similar effect as 20 mg L^{-1}. Sprays of GA_3 increased fruit firmness, had no effect on fruit weight, but increased the amount of fruit splitting. GA_3 also delayed the development of skin colour, without inhibiting fruit soluble solids accumulation. Collectively, these differences indicate the both genotype and environment play an important role in rain-induced cracking of cherries.

Table 2. Effect of pre-harvest foliar sprays of gibberellic acid on sweet fruit cracking characteristics (*Prunus avium* cvs. Sam and Bing) at harvest[z]

Spray Treatment	Cracked fruit (% by number)	Percent marketable for export (by number)	Cracking distribution (% of cracked fruit)		
			< 2 mm	2–4 mm	>4 mm
Bing					
Untreated	50.9*b*	56.0*a*	6.9*a*	8.4*a*	35.7*b*
Water	54.5*b*	52.9*a*	7.4*a*	9.7*a*	37.4*b*
4 × 10 ppm GA_3	69.8*a*	34.6*b*	4.4*b*	5.1*b*	60.2*a*
1 × 10 ppm GA_3	77.9*a*	26.3*b*	4.2*b*	4.3*b*	69.4*a*
LSD (P = 0.05, 27 df)	10.9	11.1	2.3	2.9	10.9
Sam					
Untreated	45.0	64.1	9.1	22.1	13.8*b*
Water	51.4	55.8	7.2	21.9	23.3*ab*
4 × 10 ppm GA_3	54.3	53.8	8.1	14.0	32.2*a*
1 × 10 ppm GA_3	61.9	49.1	11.0	17.7	33.3*a*
LSD (P = 0.05, 27 df)	NS(12.9)	NS(12.7)	NS(3.1)	NS(8.4)	12.5

[z]Mean separation within columns by least significant difference test; means followed by different letters are significant at P = 0.05.

Table 3. Effect of pre-harvest foliar sprays of gibberellic acid on sweet cherry fruit weight, soluble solids, size, colour and firmness (*Prunus avium* cv. Sam) at harvest

Spray treatment	Fruit mass (g)	Soluble solids (%)	Water content (%)	Fruit size (mm)			Fruit colour			Firmness (N)
				Longitudinal diameter	Suture diameter	Lateral diameter	L^*	a	b	
Untreated	7.06*b*	11.9	84.5*c*	23.0*b*	21.1*b*	24.2*c*	37.2*b*	39.6*b*	13.5*b*	0.922*b*
Water	6.97*b*	12.0	85.8*ab*	23.1*b*	20.6*ab*	22.7*d*	38.8*b*	41.3*ab*	14.9*b*	0.930*b*
4 × 10 ppm GA_3	7.24*ab*	12.2	86.3*a*	23.8*b*	22.6*ab*	25.5*b*	44.7*a*	43.3*a*	18.9*a*	0.972*a*
1 × 40 ppm GA_3	7.54*a*	12.5	85.2*abc*	24.9*a*	22.6*a*	26.1*a*	43.8*a*	42.6*a*	17.9*a*	0.969*a*
LSD (P = 0.05, 231 df)	0.39	NS(0.6)	1.1	0.39	0.37	0.49	2.4	2.2	1.6	0.216

Mean separation within columns by least significant difference test; means followed by different letters are significant at P = 0.05.
L^*a^*b system where L^* is the lightness factor ranging from black ($-L^*$) to white ($+L^*$), the a* chromaticity coordinate ranging from green ($-a^*$) to red ($+a^*$) and, b^* chromaticity coordinate ranging from blue ($-b^*$) to yellow ($+b^*$). Measured with a type 00 Durometer (Shore Instruments and Manufacturing Co., New York, USA); values converted according to the manufacturer specifications using the relationship 0.203 + 0.00908 × scale reading.

Although the total quantity of GA_3 applied in the repeated and single sprays in this experiment was identical, single applications had a much greater influence on fruit weight. The effect that both single and repeated sprays of GA_3 had on increased cracking and decreased marketable yields of both cultivars may partially be explained by an increase in fruit weight and size. Both sprays increased the fruit weight of Sam and Bing; however, the effect of single applications on Sam were not significant. Fruit from single applications of GA_3 were longer and wider in both the suture and lateral planes, whereas fruit from repeated applications were greater in the lateral diameter only, indicating that 10 mg L^{-1} GA_3 was less effective in increasing fruit weight and size. Dawood (1986) found that sprays of 15 mg L^{-1} GA_3 made 6 and 3 wk before harvest to Stella and Merton Glory also increased fruit weight and the length:width ratio of fruit. Based on the fact that he also found paclobutrazol (a growth retardant) to increase fruit weight, length, firmness, cuticle and epidermal thickness, whilst not having an effect on cracking, this seems to indicate that the relationship between fruit weight (or size) and cracking of GA_3 treated fruit may be an indirect effect.

For crack size distribution, GA_3 treatments had disproportionately fewer fruit with small cracks (<2 mm and 2–4 mm) and more fruit with larger (> 4 mm) cracks. Whether the larger cracks of GA_3-treated fruit arose from the propagation of smaller cracks appears likely, based on the skewed crack size distribution.

The effect that GA_3 sprays had on fruit finish and cuticle microcrack formation and what effect these subsequently might have on cracking is not clear. Barsy et al. (1988) found that GA_3 sprays thickened the cuticle and radial wall of epidermal cells, and concluded that the change in anatomical characteristics were responsible for reduced cracking. Sekse et al. (2005) discusses the influence of cuticular fractures with respect to fruit cracking, and it is conceivable that GA_3 influences fruit cracking indirectly by influencing the permeability or elasticity of the fruit cuticle. A conflicting report by Dawood (1986) found that sprays of both GA_3 and paclobutrazol increased the thickness of the fruit cuticle and the epidermal layers but only cracking of fruit treated with GA_3 was reduced. Looney (1985) found that GA_3 sprays reduced fruit decay, which may be directly related to direct changes in cuticle integrity and microcrack formation (Sekse et al. 2005). The influence of GA_3 on anatomical features of the fruit, and in particular cuticular cracking, is an area for further research.

Table 4. Effect of pre-harvest foliar sprays of gibberellic acid on sweet cherry fruit colour (*Prunus avium* cv. Sam and Bing) at harvest[z]

	Colour distribution[y] (%) of total fruit)			
Spray treatment	< 3 (yellow-pink)	3 (pink)	33 (red)	34 (dark red)
Bing				
Untreated	8.1*b*	39.9	32.1*a*	19.9*a*
Water	10.4*b*	37.9	34.9*a*	16.7*a*
4 × 10 ppm GA_3	40.8*a*	41.0	15.1*b*	3.2*c*
1 × 40 ppm GA_3	35.0*a*	34.5	19.6*b*	10.9*b*
LSD (*P* = 0.05, 27 df)	7.6	NS(9.2)	6.2	7.6
Sam				
Untreated	0.9	14.2*b*	50.8	34.1*a*
Water	2.6	26.5*a*	44.0	27.0*a*
4 × 10 ppm GA_3	7.6	38.3*a*	49.4	4.6*b*
1 × 40 ppm GA_3	8.4	35.6*a*	45.1	10.9*b*
LSD (*P* = 0.05, 27 df)	NS(7.8)	16.2	NS(14.6)	15.4

[z]Mean separation within columns by least significant difference test; means followed by different letters are significant at P = 0.05.
[y]Fruit classified according to four colour categories based on colour comparators developed by the Okanagan Federated Shippers (Kelowna, BC).

Increased fruit firmness following applications of GA_3 is consistent with other studies (Proebsting et al. 1973; Facteau et al. 1985a, b; Looney 1985; Facteau 1986; Dawood 1986; Kupferman 1989; Kappel et al. 2002; Özkaya et al. 2006). Gibberellic acid significantly delayed the development of skin colour, but did not have a corresponding effect on fruit soluble solids. In some instances, however, GA_3 sprays have been found to increase fruit soluble solids (Facteau et al. 1985b; Dawood 1986; Clayton et al. 2006; Lenahan et al. 2006). Since the harvest date of cherries is primarily based on fruit reaching a standard colour grade, this investigation indicates that maturity, indexed by percent soluble solids, is a better method to indicate the harvest date of GA-treated fruit since darker untreated fruit had a fruit soluble solid concentration corresponding to lighter-colour GA-treated fruit. GA treatments offer some flexibility depending on consumer preference; fruit could be marketed earlier at a lighter colour, or later with a sweeter flavour. Depending on how maturity is defined, GA_3 sprays do not appear to delay harvest as much as previously thought, since GA_3 appears to selectively inhibit anthocyanin production without directly influencing sugar accumulation.

It is not clear how GA_3 elevated the level of rain-induced fruit cracking in this study in comparison with others who have previously found the opposite effect. It is clear, however, that the exceptionally wet weather at harvest exacerbated cracking of untreated fruit beyond typical levels (data not shown), but how this might have reversed the effect of reduced cracking in reduced cracking condition is not known, since a mechanisms by which GA_3 might decrease fruit cracking have not been formally put forth. GA_3 sprays in this study significantly increased fruit weight, some size dimensions, moisture content, firmness and tended to increase fruit soluble solids. Except for fruit colour, fruit quality parameters strongly indicate that GA_3 treated fruit are more advanced in maturity, which could explain an increased susceptibility to cracking (Christensen 1972b, 1975). Furthermore, Dawood (1986) found that GA_3-treated tomatoes had a greater rate of transpiration and water uptake than untreated fruit. This suggests that GA_3 may be changing the cuticular and possibly epidermal properties of the cherry fruit, which in turn could be enhancing the rate of rain water uptake in combination with weakening the fruit skin to cracking (Glenn and Poovaiah 1989). Although differences in fruit transpiration of GA_3-treated fruit were not detected in this study, further investigation of the effect of GA_3 on changes in fruit finish and anatomical characteristics is warranted.

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