Journal of the American Pomological Society 63(3):108-114 2009

The Effect of Cultivars, Rootstocks, Fruit Maturity and Gibberellic Acid on Pedicel Retention of Sweet Cherries (*Prunus avium* L.)

Julia Wirch[1, 2], Frank Kappel[1] and Petra Scheewe[2]

Abstract

Traditional markets for fresh sweet cherries (*Prunus avium* L.) require pedicels to be attached to the fruit. Recently, there has been interest in developing markets for fresh stemless sweet cherries. This is generally motivated by the appeal of mechanically harvesting cherries due to concerns surrounding supply and cost of harvest labor. Sweet cherries destined for the processing market have traditionally been mechanically harvested and are stemless. Pedicel removal force is an important issue for the whole industry; cherries sold in the traditional format require high removal force whereas those for the stemless market need to have pedicels that have lower removal force. The objective of this study was to characterize the pedicel removal force of a range of new sweet cherry cultivars and determine the impact of maturity, rootstock, and gibberellic acid application on pedicel removal force of sweet cherries. Sweet cherry cultivars differed in the amount of force required to remove pedicels, ranging from 655 g for 'Sentennial' to 1061 g for 'Sandra Rose'. The end use of the cherries and method of harvest will determine if the pedicel removal force is a concern. As expected, maturity had an effect on stem removal force; that is as cherries matured (ripened) the stem removal force declined. Neither rootstock nor gibberellic acid had an impact on stem removal force.

The major markets for fresh sweet cherries require that pedicels are attached to the fruit when they arrive at the market. In Canada, the Canadian Food Inspection Agency (2) established that all grades of sweet cherries must be handpicked with no more than 10% of the fruit lacking pedicels, or in the case of 'Elkhorn' and 'Lambert' varieties, no more than 15%. United States standards refer to defects as "pulled stems with skin or flesh of cherry torn or which causes the cherry to leak" and there is an 8% tolerance for defects at shipping point and a 12% level for defects en route or at destination for U.S. No. 1 cherries (10). In Europe, quality standards of the European Communities regulate that all grades of cherries must be with pedicels attached (excluding sour cherries [*Prunus cerasus* L.] and "Picota" cherries, which is an established sweet cherry industry in Spain selling and exporting stemless sweet cherries in the fresh market). Grade I tolerates 10% and grade II 20% of non-damaged fruit without pedicels attached (4). Recently a segment of the industry in the state of Washington is exploring the possibility of selling fresh market cherries without pedicels. These cherries could potentially be harvested mechanically. Therefore the interest in pedicel retention force is on one hand to maintain the attachment and on the other is to facilitate detachment. In either situation there is a need to understand possible factors that can influence pedicel retention or separation.

Sweet cherries have two abscission zones (13) with the zone between the fruit and pedicel the zone of interest for this study. Differentiation of this abscission layer begins near the beginning of stage II of fruit development. At fruit maturity, separation begins directly above the stony pericarp followed later by separation at the fruit-pedicel indentation. Fracturing and separation of the cell walls occurs as abscission progresses. Ethephon promotes fruit abscission in this lower zone and reduces the fruit removal force (1). The use of ethephon has become a standard prac-

---

[1] Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C., Canada, V0H 1Z0
[2] Hochschule fur Technik und Wirtschaft (HTW) (FH) Dresden FB Landbau/Landepflege, Pillnitzer Platz 2, D-01326 Dresden, Germany

tice for the mechanical harvesting of sweet cherries destined for the brining industry. Attempts are being made to use ethephon for the harvesting of stemless sweet cherries for the fresh market (3, 12).

Nine sweet cherry cultivars were evaluated with and without ethephon and had a range of fruit removal forces of 485 to 947 g (1). All the cultivars treated with ethephon responded similarly, that is, with a reduction in the fruit removal force. They also showed with 'Windsor' sweet cherry that fruit removal force is initially large (> 1200 g), and decreases steadily as fruit enter stage III and mature.

Gibberellic acid has been used in the sweet cherry industry for many years to improve fruit quality (size and firmness) and delay maturity (5). However there is no information regarding gibberellic acid impact on pedicel attachment to fruit of sweet cherry. The effect of rootstock on pedicel attachment to sweet cherry fruit is also unknown.

The objective of this trial was to determine the effect of cultivar, rootstock, fruit maturity, and gibberellic acid on the attachment of stems to sweet cherry fruit.

Materials and Methods

General methods used for all trials were as follows. During the 2007 season, fruit samples were harvested randomly from various parts of the tree in the morning. Only sound fruit without any defects were used for analysis. For all trials, except the maturity study, fruit were harvested when they were judged to be commercially mature using the color chip number 6 of the Centre technique interprofessionnel des fruits et légumes (Ctifl) color chart (Ctifl, Paris). Fruit were taken to the laboratory and 25 fruits per replicate were analyzed for average fruit weight, fruit firmness, pedicel removal force, total soluble solids, pH and titratable acidity. Average fruit weight was determined by weighing a 25-fruit sample and dividing by the number of fruit. Fruit firmness was measured by a FirmTech2 fruit firmness measuring device (BioWorks, Wamego, Kansas). Pedicel removal force was determined using a Shimpo FGV-5X digital force gauge (Nidec-Shimpo America Corporation, Itasca, Ill.) measuring the peak force necessary to remove the pedicel. The stemless fruits were then placed into a plastic bag and the juice was expressed by crushing them. Total soluble solids concentration (TSSC) of the juice was measured using an ABBE Mark II digital refractometer (AO Scientific Instruments, Keene, N.H.). The pH was measured and the titratable acidity (TA) of a 10-mL sample of juice was measured using a 719 S Titrino autotitrator (Metrohm, Herisau, Switzerland). The number of milliliters of 0.1 N NaOH required to bring the pH to 8.1 was determined and TA was expressed as % malic acid.

Cultivars. The cultivars evaluated were: 'Santina', 'Cristalina', 'Bing', 'Samba', 'Sandra Rose', 'Summit', 'Sonata', 'Sylvia', 'Skeena', 'Lapins', 'Sweetheart', 'Staccato', 'Sovereign', and 'Sentennial' (all except 'Bing' are from the breeding program at the Pacific Agri-Food Research Centre Summerland, British Columbia). Fruits were harvested from three single-tree replicates in a completely randomized design for stem removal force and quality measurements.

Rootstocks. Fruit from three single-tree replicate 'Bing' trees planted in 1998 on the rootstocks Mazzard, Mahaleb, Gisela® 5, Gisela® 6, Gisela® 7 and Giessen (Gi) 195/20 were analyzed for stem removal force and fruit quality determinations. All fruit samples were harvested at commercial maturity on 4 July 2007.

For the cultivar and rootstock trials, the data were analyzed by one-way analysis of variance with variety and rootstock respectively as main effect by the general linear model (GLM) and means were separated by Duncan's new multiple range test (9).

Maturity. Sweet cherry varieties 'Santina', 'Lapins' and 'Sweetheart' were evaluated for maturity effect on stem removal force. Fruit was collected at four stages of maturity; 4 (red), 5 (dark red), 6 (mahagony) and 7 (black) on the Ctifl color chart. Commercial maturity is considered color 6 on the Ctifl color chart. Fruit at each maturity level were harvested from three single-tree replicates. The data for each cultivar were analyzed separately by one-way analysis of variance with maturity as main effect by the general linear model (GLM) and the means were evaluated using linear contrasts.

Gibberellic acid. GA_3 (Falgro® Tablet; Norac Concepts, Ottawa, ON) was applied to whole 'Sweetheart' cherry trees (planted in 1988), using a hand-gun to run-off. A non-ionic surfactant (Agral® 90, Norac Concepts, Ottawa, ON) and a neutral anti-foaming agent (Halt® Dow AgroSciences Canada, Inc) were added to the GA_3 mixture. Treatments consisted of applying GA_3 at the following rates and times: (1) single application of 20 ppm at 27 days after full bloom; (2) single spray of 20 ppm at 27 days after full bloom followed by a single spray of 10 ppm at straw-yellow stage of fruit development; and (3) single spray of 20 ppm at straw-yellow stage of fruit development (standard rate and timing).

Fruits were harvested twice. The first harvest took place when the unsprayed control trees were considered to be mature (26 July) and the second harvest when the GA_3 treated fruit were judged to be mature (2 Aug). Fruit at each pick were harvested for pedicel removal force and quality determinations from four single-tree replicates. The data were analyzed as a factorial analysis of variance, with GA_3 treatments and harvest time as main effects by the general linear model procedure (GLM). Planned contrasts were used to compare means of the GA_3 treatments (SAS Institute, Cary, N.C.).

Results and Discussion

All trials of cultivar, rootstock, fruit maturity and gibberellic acid were conducted in one year, 2007. No conclusions can be drawn from this work concerning any effect on pedicel removal force (PRF) due to an interaction with the environment.

Cultivar. PRF was significantly affected by cultivar, with 'Sandra Rose' and 'Bing' having the highest values of all cultivars evaluated in this trial and 'Sentennial' had the lowest PRF (Table 1). Bukovac et al. (1) reported a range

Table 1. Pedicel removal force, average fruit weight, fruit firmness, total soluble solids, and titratable acidity and of sweet cherry cultivars harvested at commercial maturity (color 6 on Ctifl color chart) in 2007.

Cultivar	Pedicel removal force (g)	Avg. fruit weight (g)	Fruit firmness (g/mm)	Total soluble solids (%)	Titratable acidity (% malic acid)
Sandra Rose	1061 a[y]	13.2 bc	270 h	22.1 ab	0.952 b
Bing	1050 a	8.7 h	323 ef	19.9 de	1.079 a
Staccato	1026 ab	12.5 cde	341 cde	20.3 bcd	0.893 bcd
Sylvia	933 bc	12.7 cd	370 bc	21.2 abcd	0.624 fg
Santina	895 cd	11.4 efg	265 h	17.8 f	0.599 g
Summit	857 cde	14.2 ab	277 gh	20.4 bcd	0.689 f
Sovereign	798 def	11.8 def	377 b	20.6 bcd	0.900 bc
Samba	769 efg	13.4 bc	337 def	19.8 de	0.819 de
Sonata	763 efg	14.7 a	332 def	20.1 cde	1.089 a
Sweetheart	726 fg	10.3 g	360 bcd	21.8 abc	1.027 a
Lapins	720 fg	12.9 cd	305 fg	19.6 de	0.805 e
Cristalina	701 fg	12.4 cdef	318 ef	18.3 ef	0.494 h
Skeena	676 fg	13.4 bc	330 def	22.5 a	0.929 b
Sentennial	655 g	11.3 fg	435 a	20.9 abcd	0.843 cde
Significance[z]	***	***	***	***	***

[z] *** = Significant at P ≤ 0.001

[y] Means within a column followed by the same letter are not significantly different (P ≤ 0.05, Duncan's new multiple range test)

of 485 g for 'Vista' to 947 g for 'Hedelfingen' sweet cherries in Michigan. Long et al. (6) have previously reported that 'Cristalina' and 'Sonata' may have pedicel retention problems. Also Millan and Charlot (7) reported that 'Samba' had low stem removal force. 'Cristalina', 'Sonata', and 'Samba' had PRF values similar to 'Sentennial', the cultivar with the lowest PRF value in this study.

Fruit quality measurements were typical of what is already known for these cultivars. All cultivars except 'Bing' were heavier than 10 g with 'Sonata', 'Summit', 'Samba', 'Sandra Rose' and 'Skeena' being the largest fruit. 'Sentennial' and 'Sovereign' are the firmest cultivars, with 'Sylvia' not significantly different from 'Sovereign', whereas 'Santina', 'Sandra Rose', and 'Summit' were the softest. 'Skeena' had the highest TSSC followed by 'Sandra Rose', 'Sweetheart', 'Sylvia', and 'Sentennial'. 'Santina' had the lowest TSSC. The cultivars 'Sonata', 'Bing', and 'Sweetheart' had the highest titratable acidity values whereas 'Cristalina' had the lowest.

Whether or not low pedicel removal force is a problem is dependent on the end use of the cherry. Currently, the fresh market is predominantly interested in sweet cherries with stems attached; however, there is some interest in marketing stemless cherries for the fresh market (11). Whiting and Smith (12) indicate that a retention force of about 300 to 400 g is required to completely harvest fruit mechanically with minimal damage to the fruit. They further report that the cultivar 'Skeena' attains those levels at optimum maturity without the use of the growth regulator ethephon. 'Skeena' at optimum maturity in our study was well above the levels cited by these workers. Whether stemless fruit will be harvested mechanically or by hand it would be advantageous to grow cultivars with a lower PRF. For the conventional market (pedicel-attached) the opposite would be true, i.e. cultivars with higher PRF would be advantageous.

Rootstock. PRF and fruit quality measurements of 'Bing' were not affected by any of the rootstocks evaluated (Table 2). Interest is increasing in the Gisela series of rootstocks and there appears to be no effect on PRF caused by these rootstocks.

Maturity. PRF declined linearly for all three cultivars as fruit matured; that is, as skin color advanced from 4 to 7 (Fig. 1; Table 3). 'Santina' and 'Lapins' appeared to have similar responses to maturity whereas 'Sweetheart' did not decline as rapidly. For most cultivars fruit firmness (decrease), TSSC (increase) and average fruit weight (increase) had significant linear responses as they matured (except 'Santina' for fruit firmness and 'Sweetheart' for average fruit weight). 'Santina' was the only cultivar that had a linear decline in titratable acidity as fruit matured. Wittenbach and

Table 2. Pedicel removal force, average fruit weight, fruit firmness, total soluble solids, and titratable acidity of 'Bing' sweet cherry on Mazzard, Mahaleb, Gisela® 5, Gisela® 6, Gisela® 7 and Giessen (Gi) 195/20 rootstock in 2007.

Rootstock	Pedicel removal force (g)	Avg. fruit weight (g)	Fruit firmness (g/mm)	Total soluble solids (%)	Titratable acidity (% malic acid)
Gisela® 5	1165	9.0	334	20.0	0.982
Gisela® 7	1117	9.3	352	21.3	0.965
Gi 195/20	1117	9.4	344	21.4	0.978
Gisela® 6	1088	9.6	346	21.3	0.980
Mazzard	1050	8.7	323	19.9	1.079
Mahaleb	1003	10.8	309	20.4	0.990
Significance[z]	NS	NS	NS	NS	NS

[z]NS = Not significant at $P \leq 0.05$

Table 3. Pedicel removal force, average fruit weight, fruit firmness, total soluble solids concentration, and titratable acidity of 'Santina', 'Lapins', and 'Sweetheart' sweet cherry at color stages 4, 5, 6, and 7 of the Ctifl color chart in 2007.

Fruit color	Pedicel removal force (g)			Average fruit weight (g)			Fruit firmness (g/mm)			Total soluble solids (%)			Titratable acidity (% malic acid)		
	Santina	Lapins	Sweet-heart	Santina	Lapins	Sweet-heart	Santina	Lapins	Sweet-heart	Santina	Lapins	Sweet-heart	Santina	Lapins	Sweet-heart
4	1089	946	996	10.0	10.0	9.9	268	367	381	14.9	15.8	19.1	0.627	0.845	1.023
5	1014	900	849	11.5	11.7	10.3	258	342	371	16.6	17.4	21.8	0.604	0.785	1.038
6	895	720	733	11.4	12.9	10.3	265	305	360	17.8	19.6	21.8	0.599	0.805	1.027
7	737	631	726	12.4	12.8	9.7	277	286	302	18.8	22.2	23.9	0.536	0.770	1.022
Linear contrast significance[z]	**	**	***	***	***	NS	NS	**	***	***	***	***	**	NS	NS

[z]NS, **, *** = Not significant, or significant at $P \leq 0.01$, or 0.001 respectively.

Bukovac (13) reported a marked decrease in fruit removal force during stage III of sweet cherry fruit development for a number of cultivars. They further reported that, for the sweet cherry cultivar 'Windsor', separation in the abscission layer began directly above the pit and resulted in the formation of a cavity. As maturity progressed, separation occurred at the fruit-pedicel indentation and extended through the abscission layer toward the vascular bundles. Abscission involved the fracturing of cell walls as well as cell separation. Richardson et al. (8) determined fruit maturity of 'Royal Ann' sweet cherry by measuring the PRF; as PRF decreased the expected percentage of fruit that was "stem-on" decreased.

Gibberellic acid. Samples were first harvested when fruit on unsprayed control trees reached commercial maturity (color 6 on the Ctifl color chart). Fruit samples from GA_3 treatment ranged in color from 5 to 6 for the single 20 ppm early treatment, and from 4 to 6 for the 20 ppm early plus 10 ppm late and the single 20 ppm late treatment (the standard commercial application timing). The second harvest was one week later, when fruit from trees with GA_3 treatment 20 ppm late were at commercial maturity. The other treatment's fruit color were color stage 7 for untreated controls, color 6 to 7 for 20 ppm GA_3 early, and color 5 to 7 for 20 ppm early plus 10 ppm late.

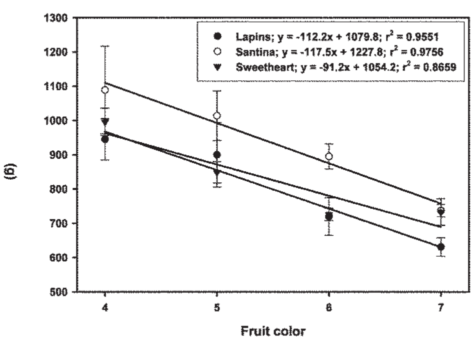

Fig. 1. Relation between pedicel (stem) removal force of 'Lapins', 'Santina' and 'Sweetheart' sweet cherry and fruit maturity as determined by skin color stage on Ctifl chart in 2007.

Table 4. Pedicel removal force, average fruit weight, fruit firmness, total soluble solids concentration, and titratable acidity of 'Sweetheart' sweet cherry treated with gibberellic acid in 2007.

Main effects	Pedicel removal force (g)	Average fruit weight (g)		Fruit firmness (g/mm)	Total soluble solids (%)	Titratable acidity (% malic acid)
GA Treatment		H1[x]	H2[x]			
Control	754 a[y]	11.2 a	10.0 b	321 b	22.7 a	1.007 b
(1) 20 ppm early	772 a	11.4 a	11.2 a	353 ab	22.1 a	1.059 ab
(2) 20 + 10 ppm	755 a	11.0 a	11.2 a	355 a	21.6 a	1.131 a
(3) 20 ppm late	822 a	11.5 a	11.3 a	375 a	21.1 a	1.127 a
Significance[z]	NS	NS	**	*	NS	**
Harvest[x]						
First	779 a	11.3 a		363 a	21.0 b	1.129 a
Second	772 a	10.9 b		338 b	22.7 a	1.033 b
Significance	NS	*		*	***	***
Interactions						
Treatment x harvest	NS	*		NS	NS	NS
Contrasts						
Control vs. GA_3	NS	**		**	NS	**
Control vs. 20 ppm	NS	**		**	NS	*
Control vs. 20+10 ppm	NS	NS		*	NS	**
Early vs. late	NS	NS		NS	NS	NS

[z] NS, *, **, *** = Not significant or significant at P ≤ 0.05, 0.01 or 0.001 respectively
[y] Means for main effects within a column followed by the same letter are not significantly different (*P* ≤ 0.05, Duncan's new multiple range test).
[x] First harvest (H1) was 26 July 2007 and second harvest (H2) was 2 Aug. 2007.

There were no significant interactions between GA_3 treatment and time of harvest except for average fruit weight (Table 4). At first harvest treatments did not differ for average fruit weight, whereas at the second harvest all GA_3-treated fruit were significantly larger than control fruit. PRF was not significantly affected by the GA_3 treatments or time of harvest. Both fruit firmness and average fruit weight responded as 'Sweetheart' typically does to GA applications, i.e., increased firmness and heavier fruit. TSSC was not significantly affected by GA, but GA treatments increased titratable acidity.

Wittenbach and Bukovac (13) have reported that GA_3 had little or no effect on the abscission zone of 'Windsor' sweet cherry explants as measured by a reduction in PRF. There have been anecdotal reports that GA can increase the PRF in some cultivars. Further work is necessary to confirm the role of GA on PRF.

Acknowledgements

We are thankful to Darrell-Lee McKenzie and Richard MacDonald for technical assistance. A special thank you to Nicole Darychuk, Danielle Francis, Erin Beulah and Chris Pagliocchini for their assistance.

Literature Cited

1. Bukovac, M.J., F. Zucconu, V.A. Wittenbach, J.A. Flore and H. Inoue. 1971. Effects of (2-chloroethyl) phosphonic acid on development and abscission of maturing sweet cherry (*Prunus avium* L.) fruit. J. Amer. Soc. Hort. Sci. 96:777-781.
2. Canadian Food Inspection Agency. 1999. Fruit inspection manuals – sweet cherries. Retrieved

16 May, 2007 from http://www.inspection.gc.ca/english/plaveg/fresh/frumanual/chercerise.shtml

3. Couey, H.M., M.W. Williams, A.G. Berlage and R.P. Larsen. 1974. Effect of ethephon and harvest method on quality of stemless sweet cherries harvested for the fresh market. HortScience 9:587-588.
4. EG-Kommission. 2004. Verordnung (EG) Nr. 214/2004 der Komission vom 6. Februar 2004 zur Festlegung der Vermarktungsnorm für Kirschen. Retrieved 20 February 2009 from http://www.lmsvg.net/filebase/uploads/EG-VN_214-2004_Kirschen.pdf
5. Kappel, F. and R. MacDonald. 2007. Early gibberellic acid sprays increase firmness and fruit size of 'Sweetheart' sweet cherry. J. Amer. Pom. Soc. 61:38-43.
6. Long, L.E., R. Núñez-Elisea and H. Cahn. 2003. A horticultural review of the newer Canadian sweet cherry varieties. Oregon State University Extension Service, The Dalles Wasco County. Retrieved May 01, 2007 from http://extension.oregonstate.edu/wasco/horticulture/Cultivars/Varieties%20Cherry%20Institute%202003.pdf
7. Millan, M. and G. Charlot. 2005. Nouvelles variétés de cerise: une gamme large et prometteuse. Infos-Ctifl 210:12-15.
8. Richardson, D.G., R.L. Stebbins, D. Kirk, D. Booster, L. Jensen and R. Cain. 1998. Brining cherry mechanical harvest: fruit maturity and machine factors involved in stem retention and bruising. Acta Hort. 468: 741-746.
9. SAS Institute, Inc. 1989. SAS/STAT user's guide. Version 6. Vol 2. SAS Institute, Inc., Cary, NC.
10. United States Department of Agriculture. 1997. United States standards for grades of sweet cherries. Effective May 7, 1971 (Reprinted – January 1997). Fresh Products Branch. Fruit and Vegetable Division. Agricultural Marketing Service. United States Department of Agriculture.
11. Whiting, M., A. Marin and L. Long. 2007. Consumers like stem-free cherries. Good Fruit Grower 58(10):14.
12. Whiting, M. and E. Smith. 2007. Effects of mechanical harvest on fruit quality and storability. Good Fruit Grower 58(10):22-24.
13. Wittenbach, V.A. and M.J. Bukovac. 1972. An anatomical and histochemical study of abscission in maturing sweet cherry fruit. J. Amer. Soc. Hort. Sci. 97:214-219.