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Effects of Preharvest Applications of Ethephon and 1-MCP to 'Bing' Sweet Cherry on Fruit Removal Force and Fruit Quality

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Abstract

Preharvest application of ethephon to 'Bing' sweet cherry (*Prunus avium* L.) trees consistently reduced fruit removal force (FRF) but also reduced fruit flesh firmness at commercial harvest. Treatment resulted in only minor effects on soluble solids concentration and titratable acidity. Red color development in fruit skin and flesh was stimulated by ethephon in some seasons. Pedicel color showed little response to ethephon and there were no effects of any treatment on fruit size. Holding sampled fruit for one or two weeks in cold storage typically resulted in fruits with higher firmness, possibly due to dehydration. Ethephon increased gum formation (gummosis) on treated trees in some, but not all, seasons. Applications of 1-MCP to sweet cherry trees within 3 days of ethephon treatment in 2003 counteracted ethephon-induced flesh firmness loss without inhibiting the reduction in FRF, but this response could not be reproduced in the following three years, despite the inclusion of various experimental sprayable formulations of 1-MCP at various concentrations, timings, spray volumes, types of sprayers and use of surfactants or other additives. Ethephon-induced changes in fruit quality may take place via pathways not regulated by 1-MCP binding or, on the other hand, binding of 1-MCP to active sites may be transitory or insufficient to initiate such changes.

Increasing cost and potential reduction in availability of agricultural labor have heightened interest in mechanical harvesting of tree fruits (17, 35). One major limitation to effective mechanical harvesting of tree fruits such as sweet cherry (*Prunus avium* L.) is the force needed to remove the mature fruit from the tree (10, 21, 23, 38). Preharvest application of ethephon stimulates sweet cherry fruit abscission from the junction of the pedicel and the fruit (1, 2, 7, 11, 38, 39), thereby reducing fruit removal force (FRF) and facilitating the mechanical harvest of "stemless" cherries (5, 18, 22, 23). In various studies, ethephon applied at concentrations from 100 to up to 1600 mg•L^{-1} in various volumes per ha at from 3 to 15 or more days before harvest have produced concentration- and time-dependent reductions in FRF as well as side effects such as gumming and/or leaf abscission (e.g., 1, 2, 4, 5, 7, 11, 18, 19, 22, 27). Several reports document cultivar differences in response to preharvest ethephon treatments (1, 2, 4, 7, 11, 19, 34). A few reports describe improvement in sweet cherry fruit recovery from ethephon applications in mechanical harvesting trials (4, 5, 27, 37).

Although considerable research has been carried out to explore preharvest ethephon effects on loosening of sweet cherry fruit, few reports provide well-supported results describing effects of such treatments on postharvest fruit quality parameters. A few reports have suggested no effects of preharvest ethephon on fruit flesh firmness at harvest (14, 24, 25), while one study reported an increase in flesh

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firmness associated with ethephon application (22). Despite the absence of scientific studies documenting preharvest-ethephon-induced reduction in sweet cherry flesh firmness, persistent reports from growers in the Washington State sweet cherry industry suggest this effect may represent a practical problem (D.C. Elfving, personal communications). Other reported effects of preharvest ethephon on sweet cherries have varied from no effect on soluble solids concentration (5, 14) to increased soluble solids (22) to reduced levels of soluble solids (6, 11), stimulation of gum formation (gummosis) on treated trees (2, 4, 5, 12, 18) or no effect on gummosis (22), stimulation of ethylene evolution from vegetative tissues (26), and stimulation of ethylene evolution from nearly mature, but not from mature, cherry fruit (24, 38). A few reports suggest preharvest ethephon may be associated with enhanced fruit size and color (7), reduced fruit size (13), no effect on fruit size (5) and lack of (11), reduced (5) or inconsistent (25) effects on fruit bruising and pitting.

In apples, 1-methylcyclopropene (1-MCP, SmartFresh, AgroFresh, Spring House, PA) inhibits perception of ethylene by competing for the binding sites for ethylene in the fruit, thereby slowing ethylene-dependent changes in fruit ripening characteristics (3, 30, 33, 36). Experimental spray applications of the SmartFresh formulation of 1-MCP to Florida *Citrus* trees treated with ethephon resulted in reduction of unwanted defoliation and gummosis while having only limited effect on the desired, ethephon-mediated fruit loosening response (8, 28, 29). The studies reported here had three objectives: 1) to evaluate preharvest ethephon treatment programs on reduction of FRF in 'Bing' sweet cherry, the most widely-grown cultivar in WA, and assess associated changes, if any, in fruit quality parameters at harvest and, in later trials, after short-term cold storage, 2) to select an ethephon treatment program showing promise for reduction of FRF in 'Bing' sweet cherry and evaluate its effects on both FRF and postharvest fruit quality, and 3) to determine whether interference with ethylene action via preharvest applications of various 1-MCP-containing formulations and mixtures offers any potential for limiting ethephon-induced negative side effects on fruit quality parameters with little or no effect on the desired reduction in FRF (8, 28, 29). AgroFresh was actively developing sprayable formulations of 1-MCP and made them available for testing during the course of these trials.

Materials and Methods

Seven experiments were conducted between 2001 and 2006. All trials employed randomized complete-block designs with at least 4 replications of single- or double-tree plots separated by single guard trees in each tree row. Where two or more tree rows were used for experiments the same season, treated rows were separated by three guard rows to protect against spray drift. A few weeks before harvest each year, all trees received a standard commercial application of gibberellic acid (GA_3) to control fruit maturity and enhance flesh firmness (31, 32). Proprietary formulations of ethephon (Ethrel®, Bayer CropScience, Research Triangle Park, NC) and 1-methylcyclopropene (SmartFresh™ and experimental sprayable formulations, AgroFresh, Spring House, PA) were applied after commercial GA orchard treatment in the trials reported here. All ethephon treatments were mixed with 0.1% v/v Regulaid® (Kalo, Overland Park, KS). 1-MCP formulations were mixed with various surfactant and other products as described for each experiment. Orchard plots were sprayed to runoff with a motorized hydraulic sprayer and handgun (Nifty Nurserycart, Rears Mfg. Co., Eugene, OR), a Proptec low-volume tower airblast sprayer (Proptec™, Ledebuhr Industries, Bath, MI), or a Turbomist piston-pump, axial-fan airblast sprayer (Slimline Mfg., Penticton, B.C., Canada). All experiments were carried out in a commercial planting of 'Bing'/Mazzard sweet cherry trees in Pasco, WA. The trees were planted in 1996 at a spacing of 5.5 x 5.5 m. Fruit sample harvests described herein were made either on the same day as or one day prior to commercial harvest. The experiments are described below.

Expt. 1, 2001. Ethephon concentration/water volume effects. All ethephon treatments were applied to two-tree plots in four randomized blocks on 15 June. Ethephon at 3 dose levels (240, 560 or 840 g active ingredient (a.i.)/ha) was applied in either 470 liters (L) water/ha (Proptec) or 1870 L water/ha (Turbo-mist). A control set of plots received neither ethephon nor water (7 treatments in each block). The mass equivalent of the force needed to remove individual fruits from their pedicels was determined on 50 cherry fruits per plot on 29 June using a Chatillon Model DFM 2 digital force gauge with a peak readout feature (Chatillon Force Meas. Products, Largo, FL) fitted with a metal hook that exerted force on the shoulders of each individual cherry fruit while the pedicel was held in the fingers to provide the resistance necessary for fruit removal. On 29 June, 50 cherries were collected from each plot and used 30 June for laboratory determinations of fruit quality. Statistical analysis was carried out by radiating regression analysis of homogeneity of slopes and 2nd-order curvatures on ethephon dose/ha for the two sprayer/water volumes/ha (9, 15).

Expt. 2, 2002. Ethephon concentration/application timing combinations. Ethephon was applied in 935 L/ha to single-tree plots in six randomized blocks on 15 and/or 21 June using the Proptec tower sprayer. Ethephon at 840 or 1120 g a.i./ha was applied to separate replicate trees in each block on 15 June. Another tree in each block received 840 g a.i./ha on 21 June only. A fourth tree in each block was treated with ethephon at 420 g a.i./ha on both 15 and 21 June. A fifth tree in each block served as an untreated control (5 treatments per block). The force needed to remove individual fruits from their pedicels was determined on 25 cherry fruits per plot on 26 June as described in Expt. 1. On 26 June, 50 cherries were collected from each plot and used 27 June for laboratory determinations of fruit quality. Statistical analysis was carried out by one-way analysis of variance followed by mean separation.

Expt. 3, 2002. Effect of applied water volume on ethephon response. All ethephon treatments were applied to single-tree plots in six randomized blocks on 15 June using the Proptec tower sprayer. Ethephon at 840 g a.i./ha was applied to separate replicate trees in each block in either 470, 935 or 1870 L water/ha. A control tree in each block remained untreated (4 treatments per block). The force needed to remove individual fruits from their pedicels was determined on 25 cherry fruits per plot on 26 June as described in Expt. 1. On 26 June, 50 cherries were collected from each plot and used 27 or 28 June for laboratory determinations of fruit quality. Statistical analysis was carried out by testing the significance of simple first- and second-order polynomial regression coefficients across water volumes.

Expt. 4, 2003. Application of SmartFresh 1-MCP. Based on results of Expts. 1-3 and those of Peterson et al. (27), ethephon at 840 g a.i./ha applied in 935 L water/ha was selected as a standard fruit-loosening program for evaluation in subsequent trials. Ethephon at 840 g a.i./ha in 935 L water/ha was applied to one single-tree plot in each of four randomized blocks on 6 June using the Proptec tower sprayer. A second tree in each block received a tank-mix of the same ethephon dose and water volume tank-mixed with 130 g a.i./ha 1-MCP as SmartFresh plus 0.1% Regulaid applied 6 June. A third tree in each block was treated with the same ethephon dose/water volume on 6 June and received an application of 130 g a.i./ha 1-MCP as SmartFresh plus 0.1% Regulaid applied 9 June. A fourth tree in each block was treated with the same ethephon dose/water volume on 6 June and received an application of 260 g a.i./ha 1-MCP as SmartFresh plus 0.1% Regulaid applied 11 June. A control set of plots remained untreated (5 treatments per block). The delayed 1-MCP applications, especially the higher 1-MCP dose applied 5 days after ethephon, were chosen to determine if later applications would effectively interfere with ethephon-mediated negative fruit-quality changes while reduction in FRF was already in progress. The force needed to remove individual fruits from their pedicels was determined on 30 cherry fruits per plot on 23 June as described in Expt. 1. Four fruit samples of 30 fruits each were collected 23

June from each plot; two of the samples were collected with pedicels intact while the other two had pedicels manually removed at harvest. One 25-fruit sample with intact pedicels and another without pedicels were used for laboratory determinations on 24 June of fruit quality at harvest. The other two samples from each plot were kept at 1°C and evaluated 1 July. Statistical analyses involved various factorial or one-way analyses of variance followed by mean separation as appropriate depending on the presence or absence of the following 3 factors: 1) bioregulator treatment combinations, 2) presence or absence of pedicels, and 3) presence or absence of fruit samples for storage. Where interactions among factors were significant, those significant interactions were identified in the presented data and levels of one factor were analyzed across levels of the other.

Expt. 5, 2004. First sprayable 1-MCP formulation trial. Ethephon at 840 g a.i./ha in 935 L water/ha was applied to one single-tree plot in each of four randomized blocks on 1 June using the Proptec tower sprayer. On 1 June, three additional single-tree plots per block were treated with the SmartFresh™ formulation of 1-MCP at either 30, 75 or 150 g a.i. MCP/ha tank-mixed with 1% v/v Prescription Treatment Ultra-fine Oil and 100 mg a.i./L disodium EDTA (SmartFresh and additives recommended by and supplied by AgroFresh) and applied dilute by handgun sprayer. Three more single-tree plots per block received both the ethephon treatment and one of the 1-MCP treatments as separate applications on 1 June. Sufficient time was allowed between applications for solution drying to occur. Three more single-tree plots per block received the same 1-MCP applications as described above, but applied on 29 May, followed by the same ethephon application on 1 June. Finally, one single-tree plot per block served as an untreated control (11 treatments per block). The force needed to remove individual fruits from their pedicels was determined on 30 cherry fruits per plot on 15 June as described in Expt. 1. Four fruit samples of 30 fruits each were collected 15 June from each plot; two of the samples were collected with pedicels intact while the other two had pedicels manually removed at harvest. One 25-fruit sample with intact pedicels and one without pedicels were used for laboratory determinations on 16 June of fruit quality at harvest. The other two samples from each plot were kept at 1°C and evaluated 1 July. Statistical analyses involved various factorial or one-way analyses of variance followed by mean separation as appropriate depending on the presence or absence of the following 3 factors: 1) bioregulator treatment combinations, 2) presence or absence of pedicels, and 3) presence or absence of fruit samples for storage. Where interactions among factors were significant, those significant interactions were identified in the presented data and levels of one factor were analyzed across levels of the other.

Expt. 6, 2005. Second sprayable 1-MCP formulation trial: concentration/timing. Ethephon at 840 g a.i./ha in 935 L water/ha was applied to one single-tree plot in each of four randomized blocks on 3 June using the Proptec tower sprayer. On 3 June, three additional single-tree plots per block were treated with an experimental sprayable formulation of 1-MCP (AFxRD-020, 2.0% w/w a.i.) in 935 L water/ha at either 1.5, 15 or 45 g a.i. MCP/ha tank-mixed with 1% v/v ECK Oil (AFxRD-020 and ECK oil recommended by and supplied by AgroFresh) and applied by Proptec sprayer. Three more single-tree plots per block received both the ethephon treatment and one of the 1-MCP treatments as separate applications on 3 June. Sufficient time was allowed between applications for solution drying to occur. Three more single-tree plots per block received the same 1-MCP applications as described above, but applied on 31 May, followed by the same ethephon application on 3 June. One additional single-tree plot per block was treated on 3 June with the ethephon application and a separate application of SmartFresh at 27 g a.i./ha in 935 l water per ha with the Proptec, similar to the treatment in 2003 that showed positive effects on control of ethephon-induced fruit flesh firmness loss. Finally, one single-tree plot per block served as an untreated control (12 treatments per block). The force needed to remove individual fruits from their pedicels was determined on 30 cherry fruits per plot on 16 June as described in Expt. 1. Four fruit samples of 30 fruits each were collected 16 June from each plot; two of the samples were collected with pedicels intact while the other two had pedicels manually removed at harvest. One 25-fruit sample with intact pedicels and one without pedicels were used for laboratory determinations on 17 June of fruit quality at harvest. The other two samples from each plot were kept at 1°C and evaluated 30 June. Statistical analyses involved various factorial or one-way analyses of variance followed by mean separation as appropriate depending on the presence or absence of the following 3 factors: 1) bioregulator treatment combinations, 2) presence or absence of pedicels, and 3) presence or absence of fruit samples for storage. Where interactions among factors were significant, those significant interactions were identified in the presented data and levels of one factor were analyzed across levels of the other.

Expt. 7, 2006. Third sprayable 1-MCP trial: dilute vs. concentrate applications. Ethephon at 840 g a.i./ha in 935 L water/ha was applied to one single-tree plot in each of five randomized blocks on 9 June using the Proptec tower sprayer. On 9 June, two additional single-tree plots per block were treated with an advanced experimental sprayable formulation of 1-MCP (AFxRD-038, 3.8% w/w a.i.) in 1870 L water/ha at either 200 or 300 g a.i. 1-MCP/ha, tank-mixed with 1% v/v IAP Oil (AFxRD-038 and IAP oil recommended by and supplied by AgroFresh) and applied by Proptec sprayer. Two more single-tree plots per block received both the ethephon treatment and one of the 1-MCP treatments as separate applications on 9 June. Two more ethephon-treated single-tree plots were sprayed dilute by handgun with the same formulation of 1-MCP at 350 mg•L^{-1} tank-mixed with either 0.1% v/v Regulaid or 0.25% v/v IAP oil. Sufficient time was allowed between applications for solution drying to occur. Both handgun applications closely approximated 1870 L water/ha. Finally, one single-tree plot per block served as an untreated control (8 treatments per block). The force needed to remove individual fruits from their pedicels was determined on 30 cherry fruits per plot on 16 June as described in Expt. 1. Four fruit samples of 30 fruits each were collected 27 June from each plot; two of the samples were collected with pedicels intact while the other two had pedicels manually removed at harvest. One fruit sample with intact pedicels and one without pedicels were used for laboratory determinations on 28 June of fruit quality at harvest. The other two samples from each plot were kept at 1°C and evaluated 12 July. Statistical analyses involved various factorial or one-way analyses of variance followed by mean separation as appropriate depending on the presence or absence of the following 3 factors: 1) bioregulator treatment combinations, 2) presence or absence of pedicels, and 3) presence or absence of fruit samples for storage. Where interactions among factors were significant, those significant interactions were identified in the presented data and levels of one factor were analyzed across levels of the other.

Following harvest, fruit were stored at 1°C overnight or for the prescribed period as described for each experiment. Fruit were warmed to 21°C before quality evaluation. Fruit flesh firmness was assessed as mass-equivalent deflection force and fruit row size (a size grade used commercially in Washington; smaller values indicate larger fruit size) was determined on 25 cherries per sample with a FirmTech Model 2 tester (BioWorks, Wamego, KS) calibrated daily with a weight and a fruit size standard. The SSC and titratable acidity (TA) were determined on a composite juice sample obtained by squeezing juice from each of 25 cherries by hand. SSC was measured using an Atago Palette PR-101 refractometer (Atago USA, Bellevue, WA) calibrated to a sucrose standard. TA was determined using a Metrohm Model 702 SM Titrino (Metrohm USA, Riverview, FL), titrating each sample to pH 8.2 with 0.1 N

KOH. External fruit color was rated visually on 25 fruit per sample from 2001-2004 using a CTIFL (CTIFL, Paris, France) rating scale from 1 (pale red) to 8 (dark mahogany). In 2005 and 2006 a new CTIFL scale was used that ranged from 1 (pale red) to 7 (dark mahogany). Internal flesh color was rated visually on 25 fruit per sample according to a system developed in the postharvest laboratory at the Tree Fruit Research and Extension Center in which color ratings ranged from 1 (yellow flesh) to 5 (mahogany flesh). Pedicel color was rated visually on 25 pedicels per sample on a scale from 1 (0-25% of pedicel brown in color) to 4 (75-100% of pedicel brown).

Trees in each trial were rated for symptoms of gummosis in late summer or early fall of the year they were treated. Gummosis was visually evaluated on two sides of each tree on a scale from 0 (no gumming) to 5 (large amounts of gum on scaffolds and branches in tree, some dripped onto soil). The two gummosis values for each tree were then averaged to create plot means for analysis.

Analyses of variance or of regression were used as previously described. Mean values were separated where appropriate with the F test alone or an F test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$). Statistical analyses were performed using the General Linear Models procedure of the Statistical Analysis System program package (SAS Institute, Cary, NC).

Results

Expt. 1 (2001). Ethephon concentration/water volume effects. Fruit removal force (FRF) at harvest decreased as ethephon dose per ha increased regardless of the sprayer/volume of water used for the application (Table 1). Fruit flesh firmness showed a similar trend, decreasing at harvest as ethephon

Table 1. Effects of ethephon concentration and application volume on force to separate fruit from pedicels (fruit removal force) and fruit quality at harvest in 'Bing' sweet cherry (Expt. 1, 2001).

Treatment[z,y]								
Ethephon (g/ha of a.i.)	Water volume (L/ha)	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Titratable acidity (%)	Row size	Skin color rating (1-8)[x]	Gummosis rating (0-5)[w]
0	0	571	359	20.7	0.847	10.0	6.5	0.1
240	470[v]	535	370	21.1	0.837	10.0	7.4	0.4
560	470	442	320	19.1	0.815	10.0	7.2	1.4
840	470	389	307	19.1	0.793	10.0	7.4	2.1
240	1870[v]	465	330	19.2	0.700	10.0	6.2	0.2
560	1870	451	317	19.0	0.805	10.0	6.4	0.6
840	1870	434	313	20.0	0.773	10.0	6.4	1.4
Significance								
Ethephon linear		***	**	*	NS	NS	NS	***
Ethephon quadratic		NS	NS	NS	NS	NS	NS	NS
Sprayer/volume effect		NS	NS	*	NS	NS	**	*
Model R^2		0.59	0.57	0.64	0.21	0.47	0.66	0.59

[z] All ethephon applied 15 June (a.i. = active ingredient). Fruit samples harvested with pedicels 29 June; harvest fruit evaluation 30 June.

[y] Statistical significance in each column determined by radiating regression analysis of homogeneity of slopes and 2nd-order curvatures on ethephon dose/ha for the two sprayer/water volumes/ha (NS - not significant; * - ˆ=0.05; ** - P=0.01; *** - P=0.001).

[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 8 (mahogany).

[w] Trees rated visually 27 Sept. 2001 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil).

[v] 470 L/ha applied with Proptec low-volume tower airblast sprayer; 1870 L/ha applied with conventional Turbomist piston pump, axial-fan airblast sprayer.

dose/ha increased; no effect of sprayer/water volume was noted. SSC generally decreased with increased ethephon dose; sprayer/water volume did influence the response but differences were small. Neither TA level at harvest nor fruit size showed any response to ethephon pretreatment. Fruit skin color did not respond specifically to ethephon dose, but overall the fruit treated with the smaller volume of water showed more developed skin color. Gummosis occurrence increased as ethephon dose increased, and was higher for the higher ethephon concentration.

Expt. 2 (2002). Ethephon concentration/application timing combinations. FRF at harvest was reduced by all ethephon treatments (Table 2). The longer before harvest the ethephon treatment was applied, the greater was the reduction in FRF. Two applications of 420 g/ha a.i., one on 15 June and a second on 21 June, reduced FRF as much as a single application of 840 g/ha a.i. applied on 15 June. Flesh firmness at harvest responded similarly: the longer between application and fruit sampling, the greater the reduction in flesh firmness, and the double application was as effective as the earlier application of twice the amount of ethephon. SSC at harvest, fruit size and skin color were all unaffected by ethephon treatment, while TA showed a small reduction when ethephon was applied twice. Gummosis was increased by the highest ethephon dose and by the double application.

Expt. 3 (2002). Effect of applied water volume on ethephon response. FRF at harvest was reduced by ethephon, with a slightly greater reduction of FRF as applied water volume was reduced (Table 3). Flesh firmness was reduced in a similar pattern. SSC, TA, fruit size and skin color were unaffected. Although the amount of ethephon applied per ha was equivalent, gummosis increased in relation to the concentration of ethephon in the applied solution.

Expt. 4 (2003). Application of SmartFresh 1-MCP. FRF at harvest was reduced similarly by ethephon alone or ethephon combined with 1-MCP (Table 4). Interestingly, while flesh firmness was decreased substantially by ethephon alone, flesh firmness was higher than control for 1-MCP alone and the ethephon-induced reduction in firmness was controlled when 1-MCP was applied the same day as ethephon or 3 days later. The higher 1-MCP dose applied 5 days later did not affect ethephon-induced flesh firmness reduction. Flesh firmness was slightly reduced in fruit that had pedicels removed during sample collection. There was no effect on flesh firmness over the 1-week cold storage period. SSC was unaf-

Table 2. Effects of ethephon concentration and application timing on force to separate fruit from pedicels (fruit removal force) and fruit quality at harvest in 'Bing' sweet cherry (Expt. 2, 2002).

Treatment[z,y] Ethephon (g/ha or a.i.)	Treatment[z,y] Date applied	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Titratable acidity (%)	Row size	Skin color rating (1-8)[x]	Gummosis rating (0-5)[w]
0	--	584 a	335 a	21.1 a	1.073 a	9.5 a	6.1 a	0.0 d
1120	15 June	333 c	275 c	20.4 a	1.006 ab	9.5 a	6.4 a	2.2 b
840	15 June	348 c	281 c	20.4 a	1.003 ab	10.0 a	6.5 a	2.3 ab
840	21 June	403 b	312 b	19.9 a	1.026 ab	9.5 a	6.1 a	1.2 c
420	15 and 21 June	355 c	355 c	19.8 a	0.958 b	9.5 a	6.5 a	2.8 a

[z] All ethephon applications with Proptec low-volume tower airblast sprayer at 935 L/ha on dates shown (a.i. = active ingredient). Fruit samples harvested 26 June and evaluated 27 June.

[y] Means in columns followed by different letters are significantly different according to F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).

[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 8 (mahogany).

[w] Trees rated visually 10 Sept. 2002 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil).

Table 3. Effects of ethephon concentration and application volume on force to separate fruit from pedicels (fruit removal force) and fruit quality at harvest in 'Bing' sweet cherry (Expt. 3, 2002).

Treatment[z,y]								
Ethephon (g/ha of a.i.)	Water volume (L/ha)	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Titratable acidity (%)	Row size	Skin color rating (1-8)[x]	Gummosis rating (0-5)[w]
0	0	522	329	21.2	1.098	9.5	7.2	0.7
840	1870	356	270	20.8	1.068	10.0	7.5	1.8
840	935	336	281	20.7	1.034	10.0	7.4	1.9
840	470	326	279	20.6	1.031	9.5	7.7	2.1
Significance								
Water volume linear		****	***	NS	NS	NS	NS	***
Water volume quadratic		****	**	NS	NS	NS	NS	**
Model R^2		0.79	0.68	0.19	0.47	0.46	0.43	0.62

[z] All ethephon applied 15 June (a.i. = active ingredient) with Proptec low-volume tower airblast sprayer. Fruit samples harvested 26 June and evaluated 27 June.
[y] Statistical significance in each column determined by quadratic polynomial regression analysis on water volume applied per ha. (NS - not significant; ** - *P*=0.01; *** - *P*=0.001; **** - *P*=0.0001).
[x] External color visually rated according to CTIFL color cards, scale 1 (pale red) to 8 (mahogany).
[w] Trees rated visually 10 Sept. 2002 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil).

fected by bioregulators or pedicel removal, but was slightly higher after 1 week of cold storage. Fruit size and gummosis rating showed no response to bioregulator treatments while pedicel color was unaffected by bioregulators but the amount of browning increased over the 1-week storage period.

Both TA and skin color displayed an interaction between bioregulators and evaluation date, with ethephon alone decreasing TA while 1-MCP preserved TA at harvest but not after a week of cold storage (Table 4). Pedicel removal was only associated with lower TA after a week of cold storage. Overall, TA was higher after 1 week of cold storage. Skin color development was increased by ethephon, retarded by 1-MCP alone, but not retarded where 1-MCP was applied after ethephon. Flesh color change was inhibited by 1-MCP alone but was unaffected by any other treatment.

Expt. 5 (2004). First sprayable 1-MCP formulation trial. FRF was unaffected by 1-MCP dose alone but was reduced by every ethephon treatment whether or not 1-MCP was applied to the same trees (Table 5). In this trial, flesh firmness did not show any response to bioregulators; pedicel removal reduced firmness, which was also higher after 2 weeks of cold storage. SSC, fruit size and gummosis rating did not change due to bioregulators; SSC was unaffected by pedicel removal but was higher after 2 weeks of cold storage.

TA was unaffected by ethephon alone or any ethephon/1-MCP dose combination, but showed a complex interaction between pedicel removal and evaluation date (Table 6). Skin color development was accelerated by ethephon, unaffected by 1-MCP alone, and accelerated by ethephon in the presence of 1-MCP; flesh color development appeared to only be stimulated when 1-MCP applied on 29 May was followed by ethephon on 1 June. Ethephon appeared to increase pedicel browning after 2 weeks of cold storage.

Expt. 6 (2005). Second sprayable 1-MCP formulation trial. FRF was strongly reduced by all ethephon treatments regardless of the presence or absence of 1-MCP (Table 7). 1-MCP alone appeared to have some effect on reducing FRF. Flesh firmness was substantially reduced by ethephon. 1-MCP (AFxRD-020) alone improved flesh firmness

Table 4. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in 'Bing' sweet cherry. Fruit quality parameters were measured at harvest and after one week of cold (1°C) storage (Expt. 4, 2003).

Treatment and application date[z,y]					Titratable acidity (%)			Skin color rating (1-8)[x]				
Ethephon (g/ha of a.i.)	1-MCP (g/ha of a.i.)	Fruit removal force(g)	Flesh firmness (g/mm)	Soluble solids concn (%)	23 June	1 July	Row size	23 June	1 July	Flesh color rating (1-5)[w]	Pedicel color rating (1-4)[v]	Gummosis rating (0-5)[u]
0	0	811 a	282 bc	18.3 a	0.812 b	0.927 a	10.0 a	7.0 b	6.6 d	4.1 ab	1.7 a	1.4 a
840 on 6 June	0 on 6 June	388 b	261 d	17.9 a	0.737 c	0.802 cd	10.0 a	7.7 a	7.7 a	4.2 a	1.5 a	2.0 a
0	130 on 6 June[t]	881 a	298 a	18.1 a	0.893 a	0.883 ab	10.0 a	6.7 c	6.9 c	3.9 c	1.5 a	1.5 a
840 on 6 June	130 on 6 June[t]	424 b	278 bc	18.5 a	0.834 ab	0.853 bc	10.0 a	7.5 a	7.5 ab	4.1 ab	1.6 a	1.6 a
840 on 6 June	130 on 9 June[t]	416 b	284 b	18.1 a	0.820 ab	0.791 d	10.0 a	7.4 a	7.4 b	4.0 bc	1.7 a	1.9 a
840 on 6 June	260 on 11 June[t]	343 b	270 cd	18.0 a	0.855 ab	0.850 bcd	10.0 a	7.6 a	7.5 ab	4.0 bc	1.6 a	1.9 a
Pedicel												
Removed		--	275 b	18.1 a	0.825 a	0.836 b	10.0 a	7.3 a	7.3 a	4.0 a	--	--
Intact		--	283 a	18.2 a	0.825 a	0.866 a	10.0 a	7.3 a	7.3 a	4.1 a	--	--
Storage												
At harvest (24 June)		--	282 a	17.9 b	0.825 b	--	10.0 a	7.3 a	--	4.0 a	1.0 b	--
Air storage (1 July)		--	276 a	18.3 a	-	0.850 a	10.0 a	--	7.3 a	4.0 a	2.2 a	--
Interactions[s]		--	NS	NS	Trt x Storage *		NS	Trt x Storage *		NS	NS	--

[z] All ethephon applied 6 June. 1-MCP applied alone 6 June or as a tank-mix with ethephon. Other 1-MCP treatments applied either 9 June or 11 June. All applications with Proptec low-volume tower airblast sprayer at 935 L/ha. Fruit samples harvested with or without pedicels 23 June; harvest fruit evaluation 24 June, post-air-storage evaluation 1 July.

[y] Means in columns within treatments followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).

[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 8 (mahogany).

[w] Fruit flesh color rated on a scale from 1 (yellow) to 5 (mahogany red).

[v] Pedicel color visually rated on a scale from 1 (0-25% of pedicel brown) to 4 (75-100% of pedicel brown).

[u] Trees rated visually 28 August 2003 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil).

[t] SmartFresh™ formulation.

[s] Interactions not significant (NS) or significant at $P \leq 0.05$ (*).

Table 5. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in 'Bing' sweet cherry. Fruit quality parameters were measured at harvest and after two weeks of cold (1°C) storage (Expt. 5, 2004).

Treatment & application date[z,y]						
Ethephon (g/ha of a.i.)	1-MCP[w] (g/ha of a.i.)	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Row size	Gummosis rating (0-5)[x]
0	0	890 a	267 a	18.2 a	10.5 a	0.2 a
840 on 1 June	0	330 b	250 a	17.7 a	10.5 a	0.7 a
0	30 on 1 June	956 a	262 a	17.4 a	10.0 a	0.3 a
0	75 on 1 June	897 a	271 a	18.2 a	10.0 a	0.4 a
0	150 on 1 June	870 a	257 a	16.4 a	10.5 a	0.4 a
840 on 1 June	30 on 1 June	333 b	245 a	17.0 a	10.0 a	0.8 a
840 on 1 June	75 on 1 June	369 b	252 a	16.6 a	10.0 a	0.2 a
840 on 1 June	150 on 1 June	359 b	247 a	17.0 a	10.0 a	0.2 a
840 on 1 June	30 on 29 May	342 b	242 a	16.8 a	10.0 a	0.6 a
840 on 1 June	75 on 29 May	346 b	246 a	17.0 a	10.0 a	1.0 a
840 on 1 June	150 on 29 May	396 b	242 a	17.0 a	10.0 a	0.5 a
Pedicel						
Removed		--	249 b	17.3 a	10.0 a	--
Intact		--	257 a	17.1 a	10.0 a	--
Storage						
At harvest (16 June)		--	248 b	16.9 b	10.0 a	--
Air storage (1 July)		--	258 a	17.5 a	10.0 a	--
Interactions[v]		--	NS	NS	NS	--

[z] All ethephon applied 1 June with Proptec low-volume tower airblast sprayer at 935 L/ha (a.i. = active ingredient). 1-MCP alone or on same day as ethephon applied dilute 1 June with hydraulic handgun sprayer. 1-MCP treatments preceding ethephon treatment applied dilute 29 May with hydraulic handgun sprayer. Fruit samples harvested with or without pedicels 15 June; harvest fruit evaluation 16 June, post-air-storage evaluation 1 July.
[y] Means in columns within treatments followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).
[x] Trees rated visually 4 August 2004 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil).
[w] SmartFresh™ formulation + disodium EDTA and ultra-fine spray oil.
[v] Interactions not significant (NS).

in a few cases but did not provide any control of ethephon-induced softening. Moreover, the SmartFresh formulation of 1-MCP (last row in Table 7) did not benefit flesh firmness. Flesh firmness was less where pedicels were removed and was higher after 2 weeks of cold storage. SSC showed no consistent response to ethephon or 1-MCP. TA tended to be lower in ethephon-treated fruit; 1-MCP did not offset this change. TA decreased after two weeks of cold storage. Fruit were a half row-size larger for controls and one ethephon/1-MCP combination, but showed no consistent change or improvement due to bioregulators. Gummosis incidence was very low in 2005 and not related to any bioregulator treatment.

Skin color development was favored by ethephon and not changed by 1-MCP (Table 8). Pedicel removal had no effect on skin color, but color was more red after two weeks of cold storage. Pedicel color in 2005 was not affected by any treatment or by cold storage.

Flesh color development was stimulated by some, but not all, ethephon treatments (Table

Table 6. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in ‘Bing’ sweet cherry. Fruit quality parameters and pedicel color rating were assessed at harvest and after two weeks of cold (1°C) storage (Expt. 5, 2004).

Treatment[z,y]			Skin	Flesh		Pedicel color (1-4)[v]	
Ethephon (g/ha of a.i.)	1-MCP (g/ha of (a.i.) and date	Titratable acidity (%)	color rating (1-8)[x]	color rating (1-5)[z]		16 June	1 July
0	0	0.800 a	4.7 c	3.9 cd		1.0 c	1.0 c
840[z]	0	0.710 a	5.2 a	4.0 bc		1.0 c	1.1 bc
0	30[u] on 1 June	0.700 a	4.4 cd	3.8 de		1.0 c	1.1 bc
0	75[u] on 1 June	0.745 a	4.7 c	3.9 cd		1.3 a	1.1 bc
0	150[u] on 1 June	0.677 a	4.2 d	3.7 e		1.0 c	1.0 c
840	30[u] on 1 June	0.729 a	5.1 ab	4.0 bc		1.0 c	1.0 c
840	75[u] on 1 June	0.735 a	4.9 bc	4.0 bc		1.0 c	1.2 ab
840	150[u] on 1 June	0.738 a	5.1 ab	4.0 bc		1.1 bc	1.2 ab
840	30[u] on 29 May	0.742 a	5.2 a	4.1 ab		1.0 c	1.2 ab
840	75[u] on 29 May	0.716 a	5.1 ab	4.2 a		1.0 c	1.3 a
840	150[u] on 29 May	0.730 a	5.2 a	4.2 a		1.2 ab	1.2 ab
Pedicel * storage					Storage		
Removed, 16 June		0.783 a	4.9 ab	3.9 b	At harvest, 16 June	1.0 b	--
Intact, 16 June		0.677 b	4.8 b	4.0 ab	After storage, 1 July	--	1.1 a
Removed, 1 July		0.717 b	5.1 a	4.1 a			
Intact, 1 July		0.737 b	4.8 b	4.0 ab			
Interaction[t]		*	*	*	Interaction[t]	*	

[z] All ethephon applied 1 June with Proptec low-volume tower airblast sprayer at 935 L/ha. 1-MCP alone or on same day as ethephon applied dilute 1 June with hydraulic handgun sprayer. 1-MCP treatments preceding ethephon treatment applied dilute 29 May with hydraulic handgun sprayer. Fruit samples harvested with or without pedicels 15 June; harvest fruit evaluation 16 June, post-air-storage evaluation 1 July.
[y] Means in columns within treatment groups followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).
[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 8 (dark mahogany).
[w] Fruit flesh color visually rated on scale from 1 (yellow) to 5 (mahogany red).
[v] Pedicel color rated on scale from 1 (0-25% of pedicel brown) to 4 (75-100% of pedicel brown).
[u] SmartFresh™ formulation + disodium EDTA and ultra-fine spray oil.
[t] Pedicel x storage or treatment x storage interaction significant at $P \leq 0.05$ (*).

8). The presence or absence of 1-MCP had no effect on flesh color. Flesh color showed a small but complex interaction between presence or absence of pedicels and storage, with the lightest flesh-color fruit having pedicels removed and rated at harvest.

Expt. 7 (2006). Third sprayable 1-MCP trial: dilute vs. concentrate application. FRF was substantially reduced by ethephon in the presence or absence of 1-MCP, while 1-MCP at 200 g a.i./ha also showed a reduced FRF (Table 9). Flesh firmness was lower for all treatments compared to controls, lower for pedicel-removed fruit and greater after 2 weeks of cold storage. One combination of ethephon and 1-MCP showed a lower SSC than control; all other treatments were not different from untreated fruit. TA was lower for all treatments receiving both ethephon and 1-MCP, but ethephon alone or 1-MCP alone did not differ from control. TA was lower after two weeks of cold storage. Fruit size at harvest in 2006 was not related to treatment. Gummosis ratings were very low in 2006, but ethephon alone slightly increased gummosis.

Fruit skin color was advanced by all eth-

Table 7. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in 'Bing' sweet cherry. Fruit quality parameters were measured at harvest and after two weeks of cold (1°C) storage (Expt. 6, 2005).

Treatment and application date[z,y] Ethephon (g/ha of a.i.)	1-MCP (g/ha of a.i.)	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Titratable acidity (%)	Row size	Gummosis rating (0-5)[x]
0	0	1038 a	302 bc	20.3 bcde	1.047 ab	9.5 a	0.1 a
840 on 3 June	0	441 d	287 de	19.9 def	0.989 cd	9.0 b	0.1 a
0	1.5 on 3 June[w]	1022 ab	329 a	20.3 bcde	1.055 ab	9.0 b	0.0 a
0	15 on 3 June[w]	936 c	322 a	21.3 a	1.065 a	9.0 b	0.2 a
0	45 on 3 June[w]	960 bc	304 b	19.8 def	1.014 bc	9.0 b	0.0 a
840 on 3 June	1.5 on 3 June[w]	462 d	298 bcd	20.1 bcde	1.014 bc	9.0 b	0.0 a
840 on 3 June	15 on 3 June[w]	461 d	288 de	20.8 abc	0.997 cd	9.5 a	0.1 a
840 on 3 June	45 on 3 June[w]	453 d	292 cde	20.9 ab	0.996 cd	9.0 b	0.2 a
840 on 3 June	1.5 on 31 May[w]	430 d	273 fg	20.0 cde	0.994 cd	9.0 b	0.1 a
840 on 3 June	15 on 31 May[w]	464 d	262 g	19.1 f	0.919 e	9.0 b	0.1 a
840 on 3 June	45 on 31 May[w]	453 d	267 g	19.6 ef	0.957 de	9.0 b	0.1 a
840 on 3 June	27 on 3 June[v]	474 d	282 ef	20.5 abcd	1.023 abc	9.0 b	0.2 a
Pedicel							
Removed		--	281 b	20.1 a	0.999 a	9.0 a	--
Intact		--	304 a	20.4 a	1.013 a	9.0 a	--
Storage							
At harvest (17 June)		--	279 b	20.1 a	1.065 a	9.0 a	--
Air storage (30 June)		--	305 a	20.3 a	0.946 b	9.0 a	--
Interactions[u]		--	NS	NS	NS	NS	--

[z] All ethephon applied 3 June with Proptec low-volume tower airblast sprayer at 935 L/ha. All 1-MCP treatments applied separately from ethephon treatments on either 31 May or 3 June with Proptec low-volume tower airblast sprayer at 935 L/ha. Fruit samples harvested with or without pedicels 16 June 2005; harvest fruit evaluation 17 June, post-air-storage evaluation 30 June.
[y] Means in columns within treatments followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test (P<0.05).
[x] Trees rated visually 8 August 2005 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil)
[w] AFxRD-020 formulation + low-viscosity ECK spray oil
[v] SmartFresh™ formulation
[u] All interactions not significant (NS)

ephon treatments; 1-MCP did not retard red color development in the presence or absence of ethephon (Table 10). Flesh color was advanced by all treatments where pedicels were removed but was unaffected where pedicels were intact. After 2 weeks of cold storage, flesh showed a slight increase in red color. Pedicel color was rated in 2006, but showed no effects of any treatment either at harvest or after cold storage (data not shown).

Discussion

Preharvest ethephon treatment consistently reduced FRF in the studies reported here. Applying 840 g a.i. of ethephon per ha resulted in FRF values near or below 400 g within a few weeks of treatment; FRF values in the range of 300-400 g provide satisfactory fruit recovery

Table 8. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in ‘Bing’ sweet cherry. Fruit quality parameters were measured at harvest and after two weeks of cold (1^{o}C) storage (Expt. 6, 2005).

Treatment and applicationd date[z,y]		Skin color rating	Pedicel color rating		Flesh color rating
Ethephon (g/ha of a.i.)	1-MCP (g/ha of a.i.)	(1-7)[x]	(1-4)[w]		(1-5)[v]
0	0	4.7 c	1.0 a		4.2 b
840 on 3 June	0	5.3 ab	1.0 a		4.3 ab
0	1.5 on 3 June[u]	4.6 c	1.0 a		4.2 b
0	15 on 3 June[u]	4.7 c	1.0 a		4.2 b
0	45 on 3 June[u]	4.6 c	1.0 a		4.2 b
840 on 3 June	1.5 on 3 June[u]	5.2 ab	1.0 a		4.3 ab
840 on 3 June	15 on 3 June[u]	5.3 ab	1.0 a		4.4 a
840 on 3 June	45 on 3 June[u]	5.2 ab	1.0 a		4.4 a
840 on 3 June	1.5 on 31 May[u]	5.4 a	1.0 a		4.4 a
840 on 3 June	15 on 31 May[u]	5.1 b	1.0 a		4.3 ab
840 on 3 June	45 on 31 May[u]	5.2 ab	1.0 a		4.4 a
840 on 3 June	27 on 3 June[t]	5.2 ab	1.0 a		1.3 ab
Pedicel				Pedicel*Storage	
Removed		5.0 a	--	Removed, 17 June	4.1 b
Intact		5.0 a	--	Intact, 17 June	4.5 a
				Removed, 30 June	4.3 ab
Storage				Intact, 30 June	4.3 ab
At harvest (17 June)		4.8 b	1.0 a		
Air storage (30 June)		5.3 a	1.0 a		
Interactions[s]		NS	NS	Interaction[s]	*

[z] All ethephon applied 3 June with Proptec low-volume tower airblast sprayer at 935 L/ha. All 1-MCP treatments applied separately from ethephon treatments on either 31 May or 3 June with Proptec low-volume tower airblast sprayer at 935 L/ha. Fruit samples harvested with or without pedicels 16 June; harvest fruit evaluation 17 June, post-air-storage evaluation 30 June.

[y] Means in columns within treatments followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).

[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 7 (dark mahogany).

[w] Pedicel color visually rated on a scale from 1 (0-25% pedicel brown) to 4 (75-100% pedicel brown)

[v] Fruit flesh color visually rated on a scale from 1 (yellow) to 5 (mahogany red)

[u] AFxRD-020 formulation + low-viscosity ECK spray oil

[t] SmartFresh™ formulation

[s] Interactions not significant (NS) or pedicel*storage interaction significant at $P \leq 0.05$ (*)

under mechanical harvesting conditions (D.L. Peterson, personal communication and Ref. 27). Hence this ethephon dose was employed in most of the trials. Flesh firmness also showed lower values than untreated fruit most years in response to preharvest ethephon treatment; the dose (amount of ethephon applied per ha) had a much greater effect on both FRF and flesh firmness than the volume of water used to apply that ethephon (concentration). Flesh firmness values and the magnitude of differences in flesh firmness between treatments and controls varied from year to year, likely due to a combination of prevailing temperature conditions and fruit maturation. Both FRF and flesh firmness were reduced to a greater extent the longer the duration between treatment and fruit sampling. In these

Table 9. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in 'Bing' sweet cherry. Fruit quality parameters were measured at harvest and after two weeks of cold (1°C) storage (Expt. 7, 2006).

Treatment[z,y] Ethephon (g/ha of a.i.)	1-MCP (g/ha of a.i.)	Fruit removal force (g)	Flesh firmness (g/mm)	Soluble solids concn (%)	Titratable acidity (%)	Row size	Gummosis rating (0-5)[x]
0	0	885 a	287 a	19.2 ab	1.243 a	9.5 a	0.0 b
840	0	342 c	236 cd	19.2 ab	1.233 a	9.5 a	0.4 a
0	200[w]	780 b	263 b	19.7 a	1.195 ab	9.5 a	0.0 b
0	300[w]	846 ab	260 b	19.7 a	1.206 ab	9.5 a	0.2 ab
840	200[w]	374 c	231 d	18.4 bc	1.124 c	9.5 a	0.0 b
840	300[w]	344 c	240 c	18.1 c	1.111 c	9.5 a	0.0 b
840	350 + Regulaid[v]	323 c	243 c	19.9 a	1.164 bc	9.5 a	0.1 b
840	350 + IAP oil[v]	336 c	239 cd	19.1 ab	1.136 b	9.5 a	0.0 b
Pedicel							
Removed		--	247 b	19.3 a	1.171 a	9.5 a	--
Intact		--	253 a	19.0 a	1.182 a	9.5 a	--
Storage							
At harvest (28 June)		--	233 b	19.4 a	1.245 a	9.5 a	--
Air storage (12 July)		--	267 a	18.9 b	1.110 b	9.5 a	--
Interactions[u]		--	NS	NS	NS	NS	NS

[z] Ethephon applied 9 June with Proptec low-volume tower airblast sprayer at 935 L/ha. AFxRD-038 formulation 1-MCP treatments applied 9 June with Proptec low-volume tower airblast sprayer at 1870 L/ha or dilute with hydraulic handgun sprayer. Fruit samples harvested with or without pedicels 27 June; harvest fruit evaluation 28 June, post-air-storage evaluation 12 July.

[y] Means in columns within treatments followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P<0.05$).

[x] Trees rated visually 1 August 2006 on a scale from 0 (no gumming) to 5 (large amounts of gum in tree, some dripped onto soil)

[w] AFxRD-038 formulation + low-viscosity IAP spray oil

[v] AFxRD-038 formulation. Applied dilute with handgun

[u] All interactions not significant (NS)

studies, double application of half the amount of ethephon each time neither improved fruit loosening nor reduced fruit firmness loss compared to a single application of twice as much ethephon. Flesh firmness was higher most years in fruit that did not have pedicels removed; it is likely that the physical process of pedicel removal at harvest may have had some effect on flesh texture. The higher flesh firmness values after cold storage may reflect some degree of water loss, although no fruit showed overt signs of shrivel.

SSC and TA showed little response to ethephon in most seasons. Where a significant response was noted, both parameters tended to be decreased in ethephon-treated fruit, similar to the observations of Bukovac et al. (6) and Couey et al. (11). Both SSC and TA responded differently to cold storage in different seasons; no clear pattern of behavior was observed for either parameter.

Fruit size at harvest met commercial acceptance standards each year. Fruit size was not influenced by any treatment or factor during the course of these studies, but both fruit skin and flesh red color development were increased some years by ethephon treatment. Skin and flesh color development showed complex, interactive effects between treatment and storage most years, but differences

Table 10. Effects of ethephon and 1-methylcyclopropene (1-MCP) on force to separate fruit from pedicels (fruit removal force) and fruit quality in 'Bing' sweet cherry. Fruit quality parameters were measured at harvest and after two weeks of cold (1°C) storage (Expt. 7, 2006).

Treatment[z,y]		Skin color rating (1-7)[x]	Flesh color rating (1-5)[w]	
Ethephon (g/ha of a.i.)	1-MCP (g/ha of a.i.)		Pedicel removed	Pedicel present
0	0	4.8 d	4.2 d	4.7 a
840	0	5.8 a	4.8 ab	4.9 a
0	200[v]	5.0 d	4.7 bc	4.8 a
0	300[v]	5.1 cd	4.7 bc	4.6 a
840	200[v]	5.5 ab	4.9 a	4.9 a
840	300[v]	5.3 bc	4.8 ab	4.9 a
840	350[u] + Regulaid	5.7 a	5.0 a	4.9 a
840	350[u] + IAP oil	5.6 a	4.9 a	4.9 a
Pedicel * storage				
Removed, 28 June		5.5 a	--	--
Intact, 28 June		5.4 ab	--	--
Removed, 12 July		5.2 b	--	--
Intact, 12 July		5.3 ab	--	--
Storage				
28 June		--	4.7 b	--
12 July		--	--	4.8 a
Interactions[t]		*	*	

[z] Ethephon applied 9 June with Proptec low-volume tower airblast sprayer at 935 L/ha. AFxRD-038 formulation 1-MCP treatments applied 9 June with Proptec low-volume tower airblast sprayer at 1870 L/ha or dilute with hydraulic handgun sprayer. Fruit samples harvested with or without pedicels 27 June; harvest fruit evaluation 28 June, post-air-storage evaluation 12 July.
[y] Means in columns within treatment groups followed by different letters are significantly different according to F-test or F-test followed by the Waller-Duncan Bayesian k-ratio test ($P \leq 0.05$).
[x] Fruit skin color visually rated according to CTIFL color cards, scale 1 (pale red) to 7 (dark mahogany).
[w] Fruit flesh color visually rated on a scale from 1 (yellow) to 5 (mahogany red)
[v] AFxRD-038 formulation + low-viscosity IAP spray oil
[u] AFxRD-038 formulation. Applied dilute with handgun
[t] Pedicel*storage and storage*treatment interactions significant at $P \leq 0.05$ (*)

were minor in a horticultural sense. Pedicel color was largely unaffected by ethephon, but tended to show more brown color after cold storage in two of four seasons in which this parameter was evaluated.

In 2003, application of SmartFresh 1-MCP appeared to both retard the cherry flesh firmness loss observed in control fruit and counteract the loss of firmness induced by ethephon treatment. At the same time, reduction in FRF produced by ethephon treatment was not affected by 1-MCP. This differential response in FRF/firmness was similar in some respects to the differential defoliation/fruit loosening effect reported by Pozo and Burns (28) and Pozo et al. (29) when both ethephon and SmartFresh 1-MCP were applied to *Citrus* trees. Unlike the experience in *Citrus*, however, gummosis in sweet cherry trees receiving both bioregulators was not reduced or inhibited by 1-MCP in any season regardless of MCP formulation or concentration/dose. Applying 1-MCP later than three days after ethephon in 2003 produced no effect on firmness, even though a more concentrated solution was applied.

Although the 2003 results with preharvest

1-MCP were very encouraging, attempts to reproduce these observations in the subsequent 3 years did not succeed, despite the use of various sprayable 1-MCP formulations, amounts of applied active ingredients, adjuvants, carrier volumes, spray application methodology and application timing relative to treatment with ethephon. Concerns about possible off-gassing loss of 1-MCP, sufficient wetting of foliage and fruit or other possible problems with using the Proptec sprayer for 1-MCP treatments led to applications of 1-MCP in both 2004 and 2006 using dilute handgun application equipment. Preharvest application of similar experimental 1-MCP formulation/supplement combinations at similar concentrations with the same dilute handgun equipment to cropping apple trees produced very strong responses in fruit postharvest behavior (16), indicating that, in apple, preharvest dilute application of one of the same sprayable 1-MCP formulations used in these studies was effective for delivering this product to the tree. Dilute application of 1-MCP to sweet cherry did not affect the response.

Gong et al. (20) showed that ethylene application to mature fruit of both 'Bing' and 'Rainier' cherries stimulated fruit respiration and other postharvest changes regardless of prior treatment with 1-MCP. They proposed that these effects might occur via a process in the cherry fruit independent of binding sites for 1-MCP. Non-climacteric fruit such as sweet cherry may have different ethylene receptors with possible different functions than climacteric fruit such as apple (20). The desirable effects of 1-MCP on FRF and flesh firmness observed in 2003 remain unexplained. However, the failure of preharvest 1-MCP to control ethephon-mediated fruit flesh firmness loss and other changes in three out of four years in these studies despite the variety of approaches used to try to assure effective delivery of the product to the tree suggests that ethephon-induced preharvest fruit quality changes in sweet cherries may take place via pathways unresponsive to the binding of 1-MCP or that 1-MCP may not bind to active sites, may bind to active sites transiently or may bind to only a small degree in sweet cherry as opposed to apple trees.

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