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Evaluation of the Sensory, Physicochemical, and Visual Characteristics of a Sweet Cherry Cultivar Treated in a Commercial Orchard with a Cherry Cuticle Supplement when a Rainfall Event Does Not Occur

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SUMMARY. The splitting of sweet cherry (*Prunus avium* L.) just before harvest can be a considerable problem in the Okanagan Valley (BC, Canada). In an attempt to minimize economic losses, growers apply a commercial cherry cuticle supplement in anticipation of a rainfall event. However, it is unknown if this product affects flavor, texture (crispness, firmness, and juiciness), or visual characteristics (stem browning, pitting, and pebbling) of sweet cherry. Therefore, this research was undertaken to evaluate the effects of a cherry cuticle supplement on the sensory, physicochemical, and visual characteristics of 'Skeena' sweet cherry. Firmness measurements were assessed with a fruit-firmness tester, whereas sensory determinations were assessed at first bite (whole-cherry crispness) and after multiple chews (flesh firmness) by a panel of 14 trained panelists. Fruit treated with the cherry cuticle supplement had lower instrumental firmness compared with the control, which was most pronounced after 28 days, with a reduction of 0.53 N. Treated fruit also had significantly lower sensory firmness and higher juiciness than the control fruit. Fruit treated with the cherry cuticle supplement had reduced water loss, less pitting, and lower stem-pull force, resulting in higher frequency of detachment of the stems. Further research would be necessary to evaluate the effects with other cultivars, and in years with rainfall events, as well as when hydrocooling is used.

Considerable rainfall can occur in the Okanagan Valley (BC, Canada) around the time that sweet cherries approach maturity. This can result in splitting or cracking of the cherries just before harvest. Cracking can occur deep into the flesh, at the stem end, the calyx end, and the cheeks (Balbontín et al., 2013), making them unsalable. Many factors influence the severity of cracking, including cultivar, fruit maturity, crop load, fruit firmness, orchard irrigation status, duration of rainfall, and temperature (Rupert et al.,

1997). Balbontín et al. (2013) reviewed the literature regarding the cultural practices, physiology, biochemistry,

and genetics in relation to cracking in sweet cherry. Yet, a complete solution is not yet available.

Recently, Measham et al. (2014) has shown that different water-uptake pathways are responsible for cracking at the calyx (apical) and stem ends of the fruit compared with cracking on the side of the fruit. The degree of cherry cracking is known to be cultivar-dependent (Andris, 2003; Hanrahan, 2014; Lane et al., 2000); however, growers do not choose a sweet cherry cultivar based on cracking susceptibility when establishing a new orchard. Nevertheless, growers want to protect their fruit. The prevalence of cherry cracking can be reduced through the use of orchard covers to protect the fruit (Børve et al., 2003; Meland et al., 2014), air-blast sprayers or helicopters to blow rainwater (dry) off the fruit (Wheat, 2015), calcium sprays (i.e., calcium nitrate or calcium chloride) to reduce osmotic potential of the fruit during rainfall events (Lang et al., 1998; Rupert et al., 1997), and prophylactic hydrophobic films to protect the fruit (Schrader and Sun, 2006).

Two commercial cherry cuticle supplements, RainGard® (Valent; Walnut Creek, CA) (Valent, 2016) and Parka+™ (Cultiva; Las Vegas, NV), are available in the marketplace to reduce the incidence of cracking or delay the cracking of fruit (Schrader and Sun, 2006). The cherry cuticle supplement, Parka+™, was previously known as SureSeal until commercialization in 2013. It is made of an elastic organic biofilm of edible components (Kaiser et al., 2014). Although its split-prevention characteristics have been documented (Cultiva, 2015; Kaiser et al., 2014), little is known about the impact of the cherry cuticle supplement on the sensory attributes and other indices of quality, such as stem-pull properties and visual characteristics. The presence of a stem protects the fruit from

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
29.5735	fl oz	mL	0.0338
9.3540	gal/acre	L·ha ⁻¹	0.1069
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
4.4482	lbf	N	0.2248
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

microbiological degradation (Kalia and Gupta, 2006) and is associated with fruit freshness (Toivonen, 2015). Its condition is indicative of overall sweet cherry quality.

Although proprietary information sheets describe the cherry cuticle supplement as colorless and odorless (Cultiva, 2015), no objective information is available on its impact on flavor, textural attributes (crispness, firmness, and juiciness), and visual characteristics (stem browning, pitting, and pebbling), particularly after storage. Therefore, this research was performed to assess the effect of the cherry cuticle supplement Parka+™ on the sensory, physicochemical, and visual characteristics of sweet cherry after 1, 7, and 28 d storage at 0.5 °C.

Materials and methods

HARVEST AND STORAGE OF FRUIT. ‘Skeena’ sweet cherries (Kappel et al., 2000) were harvested from a commercial orchard in Summerland, BC, Canada, on the morning of 9 July 2015. The cherry cuticle supplement was applied using an air-blast sprayer (Turbo-Mist; Slimline Manufacturing, Penticton, BC, Canada) using two applications, the first at late straw color and the other 7 to 10 d later, as per manufacturers’ recommendations (≈100 gal/acre). The entire orchard was sprayed, with the exception of one row of fruit which were designated untreated (control) along an outer row of the block. This row was not an edge row but rather an untreated row in an orchard containing multiple sweet cherry cultivars. The orchard was uniform in terrain and soil composition, and row effects were not anticipated. To further ensure that the untreated fruit were unaffected by overspray, only the outer halves of untreated trees were

harvested. All fruit were representatively sampled.

The 2015 growing season was uncharacteristically dry, without rain during the harvest period (Government of Canada, 2015). As such, the work was preliminary in nature; additional data will be collected as the opportunity arises.

Fruit were sorted to remove culls (<12%) and to obtain a more homogeneous level of ripeness (maturity), as determined using the seven-category Center Technique Interprofessionnel des Fruits et Légumes (CTIFL) color chart (CTIFL, Paris, France). Fruit in the 4.5 to 5 color range were retained for the study.

Fruit were packed in 1-lb clamshells (Cool Pak LLC, Oxnard, CA) and fitted with paper liners (3 × 5⁵/₈ inches) to absorb moisture for evaluation after 1, 7, or 28 d of storage. The packed clamshells with the control and treated fruit, each containing 25 cherries, were cooled to 0.5 °C, then placed in commercial modified atmosphere packaging (MAP) bags (freshLOK; Shields Bag and Printing, Yakima, WA). The bags were tightened around the clamshells to avoid excessive headspace and stored at 0.5 ± 0.1 °C for 1, 7, or 28 d. The MAP bags achieved a steady-state atmosphere passively (Kappel et al., 2002) from the natural respiration of the fruit. Oxygen and carbon dioxide concentrations would be expected to be in the range of 5% to 8% and 9% to 16%, respectively (Toivonen et al., 2007).

SENSORY EVALUATION. At each storage interval (1, 7, and 28 d), five clamshells of treated and five clamshells of control fruit were removed from storage and pooled for sensory analysis. Fruit were washed in chlorinated water (30 mg·L⁻¹ sodium hypochlorite), placed in 2.5-fl oz sample cups labeled with three-digit blinding codes, and equilibrated to room temperature for a minimum of 1 h before the sensory assessment. Panelists rated the intensity of five sensory attributes [whole-cherry crispness, flesh firmness, sweetness, tartness, and cherry flavor (Table 1)] on 100-unit unstructured line scales using sensory software (Compusense five®; Compusense, Guelph, ON, Canada). Each sensory scale was visualized on a computer monitor and labeled at 10 and 90 units, with the terms “low” and “high”

intensity, respectively. The sensory scales used in this study were identical to those used by Cliff et al. (1996) and Dever et al. (1996), but without the use of physical standards. The texture/flavor assessments were conducted in individual tasting booths fitted with red lights. The red lights served to mask color differences, if any, among the fruit. Five replicate assessments were conducted sequentially during one visit. Coded samples were presented in random order on a white tray.

Panelists (*n* = 14) were selected for the study based on interest and availability. All were staff from Agriculture and Agri-Food Canada at the Summerland Research and Development Center Summerland, BC, Canada. The group consisted of four men and 10 women ranging in age from 20 to 50 years, with limited prior sensory experience. A short training session was conducted at the start of each visit to familiarize panelists with the rating scale, the method of assessment, and the definitions of the sensory attributes (Table 1).

PHYSICOCHEMICAL AND VISUAL CHARACTERISTICS OF QUALITY. The percentage of splits was determined on the entire quantity of control (≈52 kg) and treated (≈52 kg) fruit, and expressed on a weight basis. The physicochemical and visual characteristics of quality were conducted concurrently with sensory analysis on three replicate samples, consisting of 25 fruit which were randomly sampled and warmed to room temperature. Weight loss was determined by weighing the samples (25 fruit) at the start and end of the storage period, and expressing the change in weight as a percent. Firmness and size were determined using a fruit-firmness tester (FirmTech 2; Bioworks, Wamego, KS) that recorded the force to depress the fruit 1 mm. Measurements were determined twice on each fruit; the first measurement set the cherry in the dimple impression on the turntable, and the second measurement was recorded. Such a procedure ensured the best reproducibility of the determinations. Firmness measurements were recorded in g-force and converted to Newton, whereas size determinations were reported in mm.

Visual assessments were conducted on a laboratory benchtop under natural light. Stem browning was assessed by recording the number of

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Table 1. Sensory attributes used for evaluating ‘Skeena’ sweet cherry by the trained panel ($n = 14$) on 100-unit unstructured line scales, labeled at 10 and 90 units with the terms “low” and “high” intensity, respectively.

Attribute	Definition
Whole-cherry crispness	When biting the cherry nose with your front teeth, the pressure build up and associated “crunching” sound that is heard as the tissue breaks or shatters. Assess on first bite.
Flesh firmness	The resistance to compression when the cherry is chewed between the molar teeth. Assess after repeated chewing.
Juiciness	The relative juice released when compressing the cherry with the molar teeth. Assess after repeated chewing.
Sweetness	The taste stimulated by sugars. Assess after repeated chewing.
Tartness	The taste stimulated by acids. Assess after repeated chewing.
Cherry flavor	All fruity cherry flavors (tree-ripened aromatics) not including sweet and tart. Assess after repeated chewing.

fruit in each of the following four categories: 1 = 0% to 25%, 2 = 26% to 50%, 3 = 51% to 75%, and 4 = 76% to 100% of the stem was brown (Toivonen, 2014, 2015; Toivonen and Kappel, 2012). The severity of pitting was assessed by recording the number of pitted fruit in each of the following four categories: 1 = none, 2 = slight, 3 = moderate, and 4 = severe (Kappel et al., 2006; Toivonen, 2014); whereas the severity of pebbling was assessed by recording the number of fruit in each of the following three categories: 1 = none, 2 = slight, and 3 = severe (Toivonen and Kappel, 2012).

Stem-pull force was measured using a digital force gauge (FGE-5XY; Shimpo Instruments, Cedarhurst, NY) in kilograms-force and converted to Newton.

Juice was extracted from each 25-cherry sample. The stems were removed, and fruit were placed in a resealable bag. Juice was extracted by squeezing the bag by hand. Titratable acidity (TA) was determined using an automatic titrator (848 Titrino plus; Metrohm, Herisau, Switzerland) and reported as grams malic acid per liter of juice. Soluble solid concentrations (SSCs) were determined using a portable refractometer (Refracto 30PX; Mettler Toledo, Columbus, OH) and reported as percent.

DATA ANALYSIS. Preliminary three-factor analyses of variance (ANOVAs) were conducted on sensory data at each storage period (1, 7, and 28 d) to evaluate panel performance. Main effects (panelist, replicate, and treatment) and two-factor interactions (panelist $\times$ replicate, panelist $\times$ treatment, and replicate $\times$ treatment) were analyzed. Panelist and panel performance were evaluated using the methodology as described in the literature (Douglas et al., 2001; Guinard and Cliff, 1987; King et al., 2013).

Once panelist and panel performance were demonstrated, data analysis was conducted to evaluate treatment, storage period, and treatment $\times$ storage period effects using a two-factor ANOVA. F-values were calculated and mean responses were discriminated using Fisher’s least significant difference (LSD) tests ($\alpha = 0.05$). This particular post hoc test is commonly used in sensory evaluation (O’Mahony, 1986).

The two-factor ANOVAs were subsequently conducted on the physicochemical (instrumental and compositional) determinations (firmness, size, stem-pull force, TA, and SSC). F-values were calculated, and mean responses were discerned using Fisher’s LSD tests ($\alpha = 0.05$). ANOVA calculations were performed using SAS software (version 9.3; SAS Institute, Cary, NC). Preliminary examination of weight-loss values revealed extremely small changes ($\leq 1\%$) compared with commercially acceptable values ($\approx 5\%$) (Holcroft, 2015); therefore, only average values were reported, and the weight loss was not analyzed further.

Because the visual attributes’ scales (visual browning, pitting, and pebbling) were categorical (nominal) in nature, nonparametric chi-square (χ^2) statistical tests were performed. The frequency counts were pooled over the three replications (3 samples $\times$ 25 cherries = 75 fruit). Pearson χ^2 tests of independence were performed using a two-way classification: treatment (control and cherry cuticle supplement) and severity (three- or four-point categories), as described above.

However, when extremely low or zero frequency counts occur in a few categories, it is recommended that categories be combined (O’Mahony, 1986). Therefore, the categories were simplified (pooled), and combined frequency counts were reported: stem browning ($\leq 25\%$ stem browning, $> 25\%$

stem browning), pitting (no pitting, pitting) and pebbling (no pebbling, pebbling). Calculations were performed using Excel (version 2010; Microsoft, Redmond, WA) and verified using an on-line statistical calculator (Preacher, 2001).

Results and discussion

PRELIMINARY ASSESSMENT OF PANEL PERFORMANCE. Panel performance was evaluated using a three-factor ANOVA. Significant panelist effects were observed for all six sensory attributes at all storage periods (Table 2). This represents differences in how panelists use the scale and is not unusual (Guinard and Cliff, 1987; King et al., 2013). Significant replicate effects were observed for five and three attributes after 1 and 7 d storage, respectively. This is also not unusual and reflects panel and cherry variation. Panelist $\times$ replicate interactions were significant for all attributes and storage periods with the exception of tartness at 7 d and juiciness after 28 d storage, and represents panelist irreproducibility. Despite training, some panelist irreproducibility is generally tolerated in sensory analysis (Guinard and Cliff, 1987; King et al., 2013). One significant panelist $\times$ treatment effect was observed for tartness assessed after 1 d storage. This significant interaction could not be eliminated by deleting panelists’ data. No replicate $\times$ treatment effects were observed, reflecting that the treatment effects were similar from replication to replication. Because panel performance was considered satisfactory, an ANOVA was conducted to assess the effects of treatment, storage period, and treatment $\times$ storage period.

SENSORY RESULTS. ANOVA of the sensory scores revealed that treatment effects were significant for two attributes (flesh firmness

Table 2. F-values for preliminary three-factor analyses of variance to evaluate panel performance for each of the storage periods (1, 7, and 28 d), for 14 panelists evaluating ‘Skeena’ sweet cherry treated with and without a cherry cuticle supplement (Parka + TM; Cultiva, Las Vegas, NV) in duplicate.

Storage period	Source	Sensory attribute ^z					
		Whole-cherry crispness	Flesh firmness	Juiciness	Sweetness	Tartness	Cherry flavor
1 d	Panelist	3.65***	5.06***	4.33***	5.55***	14.19***	11.00***
	Replicate	1.91	2.84*	5.68***	2.72*	4.43**	2.56*
	Treatment	0.46	2.54	6.94*	9.09**	0.25	6.45*
	Panelist × replicate	2.00***	2.86***	2.03**	2.42***	1.85	2.36**
	Panelist × treatment	0.83	1.09	0.99	1.61	2.35*	0.77
	Replicate × treatment	0.57	0.65	0.99	0.20	0.91	0.38
7 d	Panelist	14.28***	14.01***	10.04***	10.72***	4.54***	14.59***
	Replicate	4.55**	5.33***	1.15	1.70	1.00	4.95**
	Treatment	1.95	10.34***	3.27	0.02	0.35	1.42
	Panelist × replicate	1.70*	2.36**	2.69***	1.79*	1.31	3.24***
	Panelist × treatment	1.41	1.38	1.08	0.92	0.84	1.42
	Replicate × treatment	0.75	0.31	0.92	0.35	1.24	1.47
28 d	Panelist	4.32***	3.32***	6.60***	6.12***	14.24***	9.33***
	Replicate	1.72	0.37	0.98	0.38	1.99	2.43
	Treatment	6.95*	9.99**	5.53*	0.01	0.27	0.03
	Panelist × replicate	1.93**	3.13***	1.53	2.24**	1.98**	2.51***
	Panelist × treatment	1.32	0.82	1.50	0.65	0.44	0.59
	Replicate × treatment	0.18	0.10	1.06	0.59	0.38	0.37

^zF-values followed by *, **, and *** indicate significance at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 3. F-values for the two-factor analyses of variance of the sensory attributes evaluated by 14 panelists in duplicate for ‘Skeena’ sweet cherry treated with and without a cherry cuticle supplement (Parka + TM; Cultiva, Las Vegas, NV) and stored for 1, 7, and 28 d at 0.5 °C (32.9 °F).

Source	Sensory attributes ^z					
	Whole-cherry crispness	Flesh firmness	Juiciness	Sweetness	Tartness	Cherry flavor
Treatment	1.94	8.95**	7.65**	1.44	0.40	1.63
Storage period	5.99**	4.11*	8.22***	4.35*	6.24**	2.65
Treatment × storage period	1.51	0.27	0.13	1.53	0.00	0.84

^zF-values followed by *, **, and *** indicate significance at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

Table 4. Mean scores for the sensory attributes for sweet cherry (‘Skeena’) treated with and without a cherry cuticle supplement (Parka + TM; Cultiva, Las Vegas, NV) ($n = 84$) (14 panelists × 3 storage periods × 2 replications) and stored for 1, 7, and 28 d at 0.5 °C (32.9 °F) ($n = 56$) (14 panelists × 2 treatments × 2 replications).

Main effect	Level	Mean sensory score ^z					
		Whole-cherry crispness	Flesh firmness	Juiciness	Sweetness	Tartness	Cherry flavor
Treatment	Control	55.2 a	55.3 a	50.7 b	48.4 a	44.0 a	51.1 a
	Cherry cuticle supplement	53.2 a	51.1 b	53.9 a	49.9 a	44.9 a	52.8 a
Storage Period	1 d	56.0 a	55.1 a	54.5 a	49.9 a	47.2 a	53.9 a
	7 d	50.7 b	50.5 b	49.0 b	46.6 b	45.2 a	50.0 a
	28 d	55.9 a	54.0 a	53.4 a	50.9 a	40.9 b	51.9 a

^zMeans for treatment (control, cherry cuticle supplement) and storage (1, 7, and 28 d) effects with different subscripts are significantly different at $P \leq 0.05$, for each sensory attribute.

and juiciness) and that storage effects were significant for five attributes (whole-cherry crispness, flesh firmness, juiciness, sweetness, and tartness) (Table 3). The treatment × storage period term was nonsignificant for all attributes, suggesting that the pattern of response for the control and treated fruit was the same over the storage period. Mean sensory scores for the treated fruit were significantly lower for flesh

firmness than the control, with an incremental drop of 4.2 compared with the control (Table 4). Treated fruit were also juicier, with an incremental increase in juiciness of 3.2 (Table 4). This inverse relationship between firmness and juiciness has been observed by others (Cliff et al., 1996; Ross et al., 2009), where softer fruit “gave up” their juice more readily as cell breakdown occurred during mastication. In contrast, differences

were not observed sensorially for whole-cherry crispness (Table 4). The sensory assessment for whole-cherry crispness determined the “crunching” sound and textural changes associated with breaking/shattering of the cuticle (Table 1); whereas, the instrumental assessment determined the force required to depress the cuticle (nondestructively) only. Therefore, the sensory and instrumental determinations are

Table 5. F-values for the two-factor analyses of variance of the physicochemical analyses performed in triplicate for 'Skeena' sweet cherry treated with and without a cherry cuticle supplement (Parka+™; Cultiva, Las Vegas, NV) and stored for 1, 7, and 28 d at 0.5 °C (32.9 °F).

Source	Physicochemical analyses ^a				
	Firmness	Size	Stem-pull force	Titrateable acidity	Soluble solids
Treatment	11.97**	0.62	78.66***	0.47	15.54**
Storage period	58.04***	11.09**	11.12**	107.95***	1.50
Treatment × storage period	5.48*	5.79*	13.98***	1.18	2.22

^aF-values followed by *, **, and *** indicate significance at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

tracking very different underlying fruit characteristics. Mean sensory scores for four attributes (whole-cherry crispness, flesh firmness, juiciness, and sweetness) were lowest at 7 d, and "returned" to their original (1 d) values after 28 d (Table 4). This pattern of response was consistent for both the control and treated fruit. Particularly interesting was the change in whole-cherry crispness and flesh firmness. The fruit lost crispness and firmness between 1 and 7 d after harvest (Table 4), presumably from an increase in enzyme activity (Barrett and Gonzalez, 1994), autolysis of cell walls, or both (Fils-Lycaon and Buret, 1990). This softening was followed by a re-establishment of whole-cherry crispness and flesh firmness to "original levels" after 28 d (Table 4). Although such a pattern was not observed instrumentally in this research, Toivonen (2014) has reported a similar change with 'Sweetheart'. His work documented a decline in firmness (7 d) followed by an increase in firmness (>21 d), for fruit harvested at stage 4 and 5 on the CTIFL color scale. Although the underlying mechanism for this is unknown, the increase in firmness may have been associated with the cross-linking of pectin molecules (Vibhakara and Bawa, 2006) or the change in the nanostructure of the hemicelluloses within the middle lamella and cell walls (Chen et al., 2009).

Given that this pattern of firmness was not tracked instrumentally in this research, it may suggest that the instrumental and sensory assessments were not tracking the same underlying characteristics, or that panel drift may have occurred. If so, this might be alleviated in future research by the introduction of reference standards, if/when they become available for the textural attributes. Mean sensory scores for tartness were lower after 28 d (Table 4), consistent with

compositional determinations and data in the literature (Kappel et al., 2002; Kupferman and Sanderson, 2001). Mean sensory scores for cherry flavor did not differ between the treatments or among the storage periods (Table 4).

PHYSICOCHEMICAL AND VISUAL CHARACTERISTICS OF QUALITY. The percentage of splits (by weight) did not differ significantly ($P > 0.05$) between the control (4.5%) and treated (4.4%) fruit. This was, in part, attributed to the fact that there was no precipitation within 9 d of the harvest period (Government of Canada, 2015). Although research on hydrophobic coatings recommends that there be greater than 10% splits to assess product effectiveness (Hanrahan, 2014), in this research, the lack of rain and low occurrence of splits facilitated the assessment of the sensory, stem-pull force and other visual characteristics (stem browning, pitting, and pebbling) of the fruit. Among the physicochemical analyses, ANOVA revealed that treatment effects were significant for three variables (firmness, stem-pull force, and SSC), storage period effects were significant for four variables (firmness, size, stem-pull force, and TA), and treatment × storage period effects were significant for three variables (firmness, size, and stem-pull force) (Table 5). For the three variables with significant interactions, means for the combination of treatment and storage period were interpreted.

Fruit firmness was dependent on treatment and storage period (Table 5). The firmness of the control fruit increased over the 1, 7, and 28 d storage period, with larger changes than those associated with the treated fruit (Fig. 1A). The significant interaction (treatment × storage period) (Table 5) was due to the relative magnitude of the firmness change, primarily between 7 and 28 d of storage, with the

Fig. 1. Mean instrumental determinations for (A) firmness, (B) size, and (C) stem-pull force for 'Skeena' sweet cherry treated with and without a cherry cuticle supplement (Parka+™; Cultiva, Las Vegas, NV) at 1, 7, and 28 d of storage at 0.5 °C (32.9 °F). Bar charts with different letters (a–f) are significantly different according to Fisher's least significant difference tests at $P \leq 0.05$. Determinations reflect presorting of the fruit to obtain a more representative subsample for sensory analysis; 1 N = 0.2248 lbf, 1 mm = 0.0394 inch.

control and treated fruit increasing in firmness by 0.93 and 0.47 N, respectively (Fig. 1A). The largest difference in instrumental firmness between the control and treated fruit was observed after 28 d storage (0.53 N). This is close to the limits of

human detection (≈ 0.39 N) (Ross et al., 2009) and may not be detectable by consumers. Such findings are consistent with work by Kaiser et al. (2014) who also observed a slight reduction in firmness with treated fruit compared with the control. Although large weight losses can result in cuticle desiccation, the weight losses (water losses) recorded in this research were extremely small ($<1\%$) (control, 0.67%; cherry cuticle supplement, 0.52%) and would not have been expected to contribute to “false” increases in firmness. Nevertheless, the slightly lower weight loss for the treated fruit was consistent with the supplement’s role as a protective barrier.

The size of the fruit was influenced by the combination of treatment and storage period (Table 5). The fruit size decreased slightly between 1 and 7 d, with a change of -0.3 and -1.5 mm for the control and treated fruit, respectively (Fig. 1B). Smaller changes were observed after 28 d (Fig. 1B); the explanation for such findings is unknown, but may be related to the structural integrity of both the periderm and cuticle of the fruit. The stem-pull force required to detach the stem of the cherry was influenced by all experimental effects (Table 5). The control fruit at 1, 7, and 28 d had stem-pull forces which were all significantly higher than the corresponding treated fruit (Fig. 1C). Because there was very little change in

stem-pull force over time for the control fruit (5.59–5.88 N), it suggested that desiccation was unlikely a contributing factor to the reduction. In contrast, the stem-pull force for the treated fruit dropped off significantly during storage (Fig. 1C). Anecdotal remarks confirmed the ease of removal/detachment of the stems. As such, this could have considerable consequences to the industry and represents a reduction in quality for the treated fruit. It is speculated that the decrease is likely due to a direct effect of the active ingredients in the cherry cuticle supplement on loosening of the stems. Such findings are in contrast to findings by other researchers who reported an increase in stem-pull force for sweet cherry, field-treated with two applications of the cherry cuticle supplement SureSeal (aka Parka+™) (Kaiser et al., 2014). Such apparently contradictory findings may be partially explained by cultivar difference or the difference in incidence of splitting in the two experiments. There was an extremely low occurrence of splitting (4.5%) in this 2015 study (Summerland, BC, Canada), none of which was due to a rainfall event, and a very high occurrence of splitting (24.6%) in the 2008 study (Lofthus, Hordaland, Norway) (Kaiser et al., 2014). Extremely high rainfall (>60 mm) is expected every year in Lofthus, Hordaland, Norway, whereas rainfall events in Summerland

BC Canada can be highly variable and unpredictable, and fruit may be sprayed with a cherry cuticle supplement as a precautionary measure only.

Compositional analyses (TA and SSC) also differed for the main effects (treatments and storage period), but not the combination (treatment $\times$ storage period) (Table 5). TA did not differ between the control and treated fruit (Fig. 2A), consistent with sensory analysis (Tables 3 and 4). All fruit (control and cherry cuticle supplement) lost TA with storage (Fig. 2C), with a systematic decline across the storage periods (1, 7, and 28 d), as expected (Kupferman and Sanderson, 2001; Remón et al., 2000). Treated fruit were significantly lower in SSC than the control fruit (Fig. 2B); however, such differences were not large enough to be perceived by the sensory panel (Tables 3 and 4). These findings are in contrast to studies by Kaiser et al. (2014) and Meland et al. (2014) who reported higher SSCs in treated fruit. SSC did not change with storage (Fig. 2D), yet differences were reported sensorially (Tables 3 and 4). However, such differences in SSC (and possibly TA) may partially be attributed to the fact that fruit in this research were sorted to remove under- or over-mature fruit and to provide a more representative collection of fruit for sensory analysis. The frequency of occurrence of the visual characteristics (stem browning, pitting, and pebbling) between the control and treated fruit stored for 1, 7, and 28 d is shown in Table 6. The frequency of pitting was significantly ($\chi^2 = 4.127\text{--}4.807$, $P \leq 0.05$) different between the control and treated fruit, with a lower incidence of pitting for the treated fruit (i.e., higher number of nonpitted fruit) for each of the storage periods (Table 6). A similar pattern was observed for the frequency of pebbling ($\chi^2 = 3.692$, $P \leq 0.05$), with a trend for a lower incidence of pebbling for the treated fruit (i.e., higher number of nonpebbled fruit), but only for the 7 d storage period. Such trends confirm that the cherry cuticle supplement has a protective role in preserving the integrity of the surface of the fruit. The extremely low frequency of occurrence of stem browning at all storage periods (i.e., high number of nonbrown stems) suggested that this visual characteristic might be dropped as a quality index for cherry cuticle supplement

Fig. 2. Mean compositional determinations for (A) titratable acidity (TA) and (B) soluble solid concentrations (SSCs) for ‘Skeena’ sweet cherry treated with and without a cherry cuticle supplement (Parka+™; Cultiva, Las Vegas, NV). Mean determinations for (C) TA and (D) SSC after 1, 7, and 28 d of storage at 0.5 °C (32.9 °F). Bar charts for treatment and storage effects with different letters (a–c) are significantly different according to Fisher’s least significant difference tests at $P \leq 0.05$. Determinations reflect presorting of the fruit to obtain a more representative subsample for sensory analysis; 1 g·L⁻¹ = 0.1% (wt/vol).

Table 6. Frequency of occurrence of visual characteristics (stem browning, pitting, and pebbling) for ‘Skeena’ sweet cherry treated with and without a cherry cuticle supplement (Parka+™; Cultiva, Las Vegas, NV) and stored for 1, 7, and 28 d at 0.5 °C (32.9 °F). Higher values represent a lower incidence of occurrence (i.e., disorder-free fruit).

Storage period	Stem browning ^z		Pitting ^z		Pebbling ^z	
	Control (n = 75)	Cherry cuticle supplement ^y (n = 75)	Control (n = 75)	Cherry cuticle supplement ^y (n = 75)	Control (n = 75)	Cherry cuticle supplement ^y (n = 75)
1 d	75	75 ^x	68	74*	73	73 ^x
7 d	74	75	65	72*	61	69*
28 d	73	75	66	73*	14	14 ^x

^zCategorical scales were simplified: stem browning (1 ≤ 25%, 2 > 25%), pitting (1 = no pitting, 2 = pitting), and pebbling (1 = no pebbling, 2 = pebbling). Due to the low incidence of occurrence, only the frequency counts for category 1 were reported.

^yFrequency counts followed by * indicate significance of the χ^2 test between the control and treated fruit at $P \leq 0.05$.

^xChi-square tests were not conducted because of identical frequency counts between the control and treated fruit.

research. Such findings are consistent with research by Hanrahan (2014) with respect to stem browning but not pitting. In this research, the degree of pitting was a valuable quality index for tracking the role of cuticle supplement in preserving the integrity of the surface of the fruit.

Conclusions

This research successfully documented the sensory, physicochemical, and visual characteristics of ‘Skeena’ sweet cherry treated with a cherry cuticle supplement and stored for 1, 7, and 28 d. Treated fruit had lower incidence of pitting and weight loss. Results are consistent with the role of a cherry cuticle supplement as a hydrophobic barrier—sealing or protecting the fruit. Such effects would be advantageous to the industry. The increased incidence of stem loss, as reflected by a substantial reduction in stem-pull force, could be a serious limitation. However, it should be noted that the cherry cuticle supplement in this research was sprayed as a precautionary measure and a rainfall event did not occur. As a result, in this research, the “maximum” amount of the cuticle supplement would have been present on the fruit. Although drought conditions might have altered the water status of the tree and stem, trees in this research were irrigated and would have received a similar amount of water as they would have in a year with rainfall.

Treated fruit had significantly lower firmness compared with the control after 28 d of storage—the magnitude of which may not be of commercial significance. Nevertheless, a similar trend was observed after 7 d storage. These reductions were also observed by the sensory panel, with significantly lower flesh

firmness, in the treated fruit compared with the control fruit. This suggested that the cherry cuticle supplement may be modifying the underlying physiology of the fruit, not simply serving as a hydrophobic barrier. Concomitant with lower firmness, the treated fruit had significantly higher juiciness. Such changes were believed to reflect enhanced ripening (off the tree) with possibly enhanced solubilization and depolymerization of the cell walls (Chen et al., 2009). While the exact mechanism is unknown, it is speculated that these processes might be attributed to a modified gas exchange, enzymatic degradation, or both. As such, it would be interesting to examine the cell-wall architecture using confocal microscopy, as described by Buda et al. (2009). The cherry cuticle supplement did not influence flavor (sweetness, tartness, and cherry flavor).

In short, this research was the first of its type to report the sensory, physicochemical, and visual changes associated with a cherry cuticle supplement, Parka+™, when rainfall does not occur. Further research would be needed to verify these findings with other cultivars when similar climate conditions occur again and when hydrocooling is used.

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