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Quality and physiological responses of two late-season sweet cherry cultivars 'Lapins' and 'Skeena' to modified atmosphere packaging (MAP) during simulated long distance ocean shipping



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ABSTRACT

The production and export of late season sweet cherry cultivars continues to increase in the US Pacific Northwest (PNW). Major postharvest quality deterioration during long distance ocean shipping include flavor loss, off-flavor development, skin darkening, pedicel browning, pitting, and decay. In this research, three modified atmosphere packaging (MAP) liners with varied gas permeability were evaluated for their effect on quality deterioration and physiological changes of 'Lapins' and 'Skeena' during a simulated transit of 6 weeks at 0 °C. Results showed that MAP2 (O₂ 6.5–7.5%, CO₂ 8.0–10.0%) reduced ascorbic acid (AsA) loss and lipid peroxidation, maintained flavor by retarding titratable acid loss and bitter taste formation, and kept brighter color by retarding anthocyanin synthesis compared to the macro-perforated polyethylene liner after 4 and 6 weeks. In contrast, MAP1 (O₂ 12.0–13.5%, CO₂ 5.0–7.0%) had little benefit on maintaining fruit flavor and skin color. MAP3 (O₂ 0.5–1.5%, CO₂ ~10%), on the other hand, showed greater benefits in most of the quality attributes; however, fruit exhibited anaerobic off-flavor from a significant accumulation of ethanol, especially in 'Skeena'. All three MAP liners reduced pedicel browning and decay but did not affect pitting and splitting. In conclusion, only the MAP with the most appropriate gas permeability, which maintained O₂ 6.5–7.5% and CO₂ 8.0–10.0%, slowed down fruit senescence and maintained quality with respect to flavor and skin color of the late season sweet cherry cultivars after long distance ocean shipping.

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1. Introduction

Sweet cherries (*Prunus avium* L.) are highly perishable and have a short shelf life even under cold chain management. In the US Pacific Northwest (PNW), more than 1/3 of the sweet cherries are exported each year. The cherry industry is interested in shipping cherries by boat to long distance export markets instead of by air freight thereby reducing costs (Kupferman and Sanderson, 2001; Toivonen, 2014). While it takes 2–3 days by airfreight, the transition time by ocean shipping to export markets may range from 3 to 5 weeks after packing (Toivonen, 2014). With protracted transport, significant arrival issues can occur including loss of flavor, development of off-flavor, darkening of fruit skin color,

pitting, pedicel browning, splitting, and decay (industry communication).

Modified atmosphere packaging (MAP) is used to supplement low temperature management to delay senescence, reduce physiological disorders, and suppress decay in many fresh fruit and vegetable products (Beaudry, 1999). While numerous studies indicated the potential of MAP for extending storage/shipping life of sweet cherries (Crisosto et al., 2009; Harb et al., 2006; Lurie and Aharoni, 1997; Mattheis and Reed, 1994; Meheriuk et al., 1995, 1997; Padilla-Zakour et al., 2004; Remón et al., 2000), certain cherry cultivars had little response or responded negatively to MAP regarding respiration, flavor, texture, stem (pedicel) quality, and mold infection (Kahlke et al., 2009; Petracek et al., 2002; Stow et al., 2004) indicating that package selection is highly cultivar dependent.

The benefits of MAP on extending storage life of fresh produce are due primarily to the decreased O₂ and/or increased CO₂ concentrations and a high relative humidity surrounding the

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commodity. The steady state O₂ and CO₂ concentrations within the MAP are a result of the interaction of a number of factors including gas permeability characteristics of the film, respiratory behavior of the product, and temperature of the surrounding storage environment (Beaudry, 1999). However, MAP can induce anaerobic fermentation if the O₂ concentration decreases to the “extinction point”, a point that will not sustain aerobic respiration, or CO₂ injury if the CO₂ concentration exceeds tolerable levels (Kays and Paull, 2004). As a consequence, gas permeability of the MAP must match the respiratory behavior of the commodity at the storage/shipping temperature to ensure creating the gas combination needed to maintain quality without creating an undesirable anaerobic condition and CO₂ damage.

Sweet cherries have very different respiration rates among cultivars (Wang and Long, 2014) and there are numerous MAP liners available commercially with a wide range of gas permeabilities. Sweet cherry production in the PNW has increased roughly 2-fold over the last decade and 61% of all cherry trees planted in Oregon between 1999 and 2005 were late-maturing cultivars (USDA-NASS, 2006). The postharvest physiology of the late-maturing cultivars and their responses to MAP are poorly understood. It was reported that storage life of ‘Lapins’ cherries were 4–6 weeks in equilibrium atmospheres of O₂ 0.8% + CO₂ 4.5% at 0 °C (Meheriuk et al., 1995) and 4 weeks in O₂ 9–10% + CO₂ 7–8% at 3 °C (Padilla-Zakour et al., 2004). ‘Sweetheart’ cherries have a storage life of 4 weeks in O₂ 4.6% + CO₂ 10% or O₂ 6.6% + CO₂ 3.5% at 0 °C (Meheriuk et al., 1997). The optimum O₂ and CO₂ concentrations for maintaining quality of the late season cultivars and their anaerobic injury threshold are not clear. The objective of this study was to assess fruit quality and biochemical responses of two major late-maturing cultivars (‘Lapins’ and ‘Skeena’) grown in PNW to three MAP liners that have different gas permeabilities. The goal was to provide the sweet cherry industry useful scientific information for extending shipping life with ensured long distance shipping arrival quality for these late-maturing sweet cherries cultivars.

2. Materials and methods

2.1. Fruit materials and MAP liners

Sweet cherry fruit were harvested at commercial maturity in a research block of ‘Lapins’ and ‘Skeena’ trees at Oregon State University’s Mid-Columbia Agricultural Research and Extension Center (MCAREC), Hood River, Oregon, USA (lat. 45.68° N, long. 121.52° W). Both cultivars were 15-years old, grown on Mazzard rootstock and trained to a steep leader system (Long, 2003). Fruit trees were maintained with standard cultural, fertilizer, herbicide and pesticide practices. The commercial maturity was determined as of color grade 5 according to the color comparator developed by Centre Technique Interprofessionnel des Fruit et Legumes (CTIFL), Paris, France, in which 1 = light pink and 7 = dark mahogany. Cherries were picked in the morning and immediately transported to the laboratory at MCAREC. Harvested fruit were hydro-cooled until pulp temperature reached 0–2 °C by dipping in iced water (0 °C) containing 100 mg L⁻¹ sodium hypochlorite for 5 min, and then rinsed by cold tap water (0 °C). After sorting for uniformity of size and color and freedom from defects, sound fruit with pedicels were divided into 4 treatments × 3 replications = 12 lots (8 kg/lot) and were immediately packed at 0 °C into 3 different MAP liners and a macro-perforated polyethylene liner with a perforation ratio of ~0.5% (10 holes, evenly distributed with diameters of ~2 mm) as the control. Each treatment contained three replicates (three boxes). The 3 liners, Xtend[®] (815-CH57/14, StePac, Tefen, Israel), Breatheway[®] (363-106-A, Apio Inc. Guadalupe, CA), and Primpro[®] (PP118,

Chantler Packaging Inc., Ontario, Canada) were marked as MAP1, MAP2, and MAP3, respectively. The characteristics of each MAP liner are proprietary, but they were listed in the order of gas permeability, from high to low. The liners were sealed using a “twist-and-tie” with an elastic band. After 4 weeks of storage at 0 °C and 90% RH, 110 fruit from each bag were removed for various quality measurements, and the bags re-sealed. The open and re-seal procedures were all performed very quickly to avoid a dramatic change of atmosphere in each bag. The fruit were stored for another two weeks until the final evaluation of fruit quality and analytical measurements. At each sampling time, 60 fruit were used for respiration rate and fruit quality attributes, and 50 for postharvest disorders (pitting, splitting, pedicel browning, and decay) and sensory evaluations, per replicate.

2.2. Fruit weight loss and headspace atmospheres inside the packages

The boxes of fruit were weighed initially and before and after sampling at each evaluation date. Weight loss was expressed as percentage loss of original weight. The concentrations of O₂ and CO₂ in the liners were determined using an O₂/CO₂ analyzer (Model 900151, Bridge Analyzers Inc., Alameda, CA) every day during the first week then every week until the end of the experiment. A silicon septum was glued to each MAP liner for gas sampling.

2.3. Respiration rate, ascorbic acid (AsA), malondialdehyde (MDA), and anthocyanin

Thirty fruit from each replicate box were equilibrated in air at 0 °C for 5 h before placing into hermetically sealed glass containers (960 mL) equipped with 2 rubber sampling ports at 0 °C. After 1 h incubation, headspace CO₂ concentrations were determined using a CO₂ analyzer (Model 900161, Bridge Analyzers Inc., Alameda, CA). The analyzer was configured to recirculate headspace gases creating a continuous-flow between the glass container and the analyzer. Fruit respiration rate was expressed as μg kg⁻¹ s⁻¹.

After respiration determination, the 30 fruit per box were cut into 2-mm pieces and frozen in liquid nitrogen followed by storage in a freezer (–80 °C) until analyzed for AsA, MDA, and anthocyanin levels. Spectrophotometric measurements were performed on a model Ultrospec 3100 pro spectrophotometer (Biochrom Ltd, Cambridge, England). AsA was measured based on the methods of Logan et al., (1998). Frozen fruit tissue, weighing 2 g was ground in 10 mL ice-cold 6% (v/v) HClO₄. The extract was centrifuged at 10,000 × g for 10 min at 2 °C and then the supernatant was used immediately for the measurement. A portion of the extract was neutralized with approximately one-third volume 1.5 M Na₂CO₃. Thirty to 100 μL of the neutralized samples were used to assay the AsA at 265 nm in 100 mM potassium phosphate buffer (pH 5.6), before and after 15 min incubation with 5 units AsA oxidase from Cucurbita (Sigma). The AsA content was determined from the absorbance difference (before and after 15 min incubation with AsA oxidase) and compared to a standard curve with the results expressed as mg kg⁻¹.

MDA level was measured according to Hodges et al., (1999) with some modification. Two grams of the frozen fruit tissue was ground and extracted in 5 mL 10% (w/v) trichloroacetic acid (TCA). After centrifugation at 10,000 × g for 15 min, a 2 mL aliquot of the supernatant was mixed with 2 mL of 10% TCA containing 0.6% (w/v) thiobarbituric acid (TBA). The mixture was heated to 100 °C for 20 min, quickly cooled and centrifuged at 10,000 × g for 10 min. The supernatant was collected and absorbance then measured at 450, 532, and 600 nm. The MDA concentration was calculated according to the formula: $6.45 \times (A_{532} - A_{600}) - 0.56 \times A_{450}$ and the results were expressed as mmol kg⁻¹.

Total anthocyanin was determined according to Dekazos, (1970). Two grams of the frozen fruit tissue was ground in 20 mL of acidified methanol (1% HCl). The resultant dispersion was vortexed for 2 min and the supernatant filtered through Waterman #4 filter paper. The residue were re-suspended in the same solvent and filtered over two times. The combined supernatants were centrifuged at $10,000 \times g$ for 5 min and measured at 530 nm. Total anthocyanin contents were calculated based on the molar-extinction coefficient of Idaein ($C_{21}H_{21}O_{11} \cdot 2.5H_2O$) at $E = 3.43 \times 10^4$ $L \cdot mol^{-1} \cdot cm^{-1}$ and the results expressed as $g \cdot kg^{-1}$.

2.4. Fruit quality

Thirty fruit per replicate box were equilibrated in air at $20^\circ C$ overnight. Fruit skin color was determined using a colorimeter (Model CR-2500d, Minolta, Tokyo, Japan) and the data were recorded as CIE a^* , b^* , and L^* values. Measurements were taken on opposite sides of each fruit, midway between the pedicel and calyx. L^* represents fruit skin lightness. Fruit firmness (FF) was measured using a FirmTech 2 Fruit Firmness instrument (BioWorks Inc., Wamego, KS) by determining the force (N) requirement to compress the fruit for one millimeter. After FF determination, fruit juice was prepared for soluble solid content (SSC), titratable acidity (TA), and ethanol measurements using a juicer (Acme Model 6001, Acme Juicer Manufacturing Co., Sierra Madre, CA) equipped with a uniform strip of milk filter (Schwartz Manufacturing Co., Two Rivers, WI). SSC was determined using a refractometer (Model N1, Atago, Tokyo, Japan). TA was determined by titrating 10 mL juice plus 40 mL distilled water to pH 8.1 using 0.1 N NaOH using a commercial titration system (Model T80/20, Schott-Gerate, Hofheim, Germany) and expressed as the equivalent percentage of malic acid. Five milliliter of the fruit juice and 1 g of NaCl powder were transferred into 20 mL vials and capped with crimp capes containing Teflon-coated septa (Gerstel, Inc., Baltimore, MD), well mixed and then frozen at $-80^\circ C$ until analyzed for ethanol content using headspace, solid-phase-microextraction, and gas chromatography–mass spectrometry system (Model 6890, Agilent, Santa Clara, CA) according to Bai et al., (2014). Ethanol was

quantified by using a peak size vs. concentration curve built by serially diluted five point standard solutions and expressed as $mg \cdot kg^{-1}$.

2.5. Postharvest disorders

Fifty fruit per replicate were evaluated for fruit pitting, pedicel browning, splitting, and decay. For pitting, only those fruit with >3 mm diameter symptom were considered to affect fruit appearance and thus counted as pitting. Pedicel browning was recorded for the pedicels with $>30\%$ of the entire surface browned. Any splitting and decay symptoms, regardless of severity, were recorded. All above defects were expressed as the percentage of incidence.

2.6. Sensory evaluations

After postharvest disorder evaluations, sound fruit were evaluated for sensory quality of cherry flavor, fermentative off-flavor, and bitter taste, assessed by using a trained three-member panel (the senior author and two experienced technicians) using a nine-point hedonic scale: cherry flavor (bland to intense), fermentative off-flavor (not-detectable to pronounced), and bitter taste (not-detectable to pronounced). Each member tasted 5 fruit per replicate/box. The procedures for sensory evaluation of horticultural crops described by Heintz and Kader, (1983) were utilized.

2.7. Statistical Analyses

The experiment design was completely randomized with three replicates. The data were subjected to analysis of variance (ANOVA) using StatSoft® Statistica version 6 (StatSoft, Tulsa, OK). When appropriate, means were separated by Fisher's Protected LSD test at $P < 0.05$.

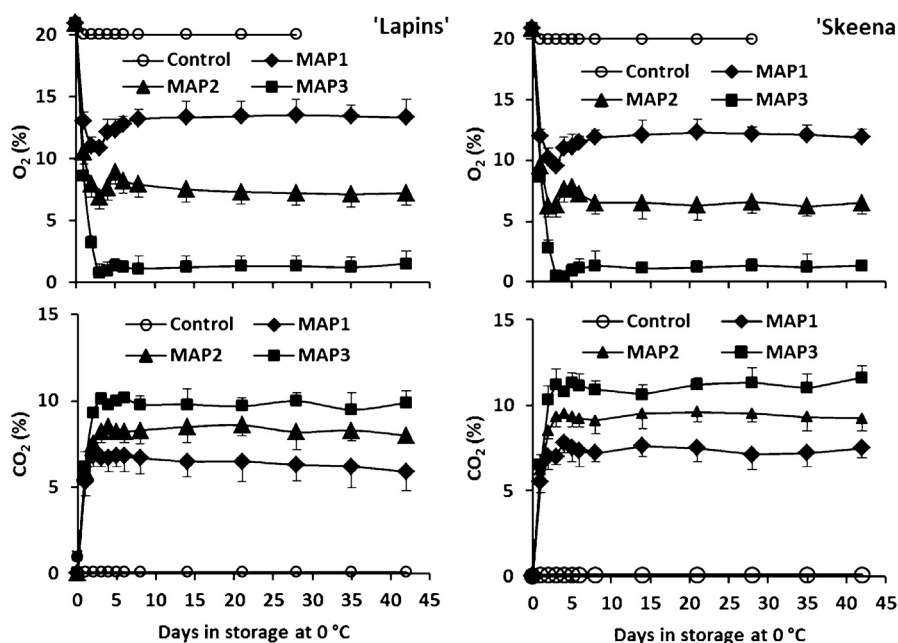


Fig. 1. O₂ and CO₂ concentrations in 3 different modified atmosphere packages (MAP1–3) and a macro-perforated polyethylene liner (control) containing 'Lapins' and 'Skeena' cherries stored at $0^\circ C$. Vertical bars represent standard deviations.

3. Results

The initial quality parameters were: FF = 2.59 N, SSC = 18.9%, and TA = 0.83% for 'Lapins'; FF = 3.11 N, SSC = 20.6%, and TA = 0.92% for 'Skeena'.

3.1. Weight loss, and O₂ and CO₂ concentrations in MAP

The accumulative weight losses were <1% and there was no difference in weight loss among the different MAP treatments and the control ($P < 0.05$) for 'Lapins' and 'Skeena' after 6 weeks at 0 °C (data not shown). The concentrations of O₂ and CO₂ in all MAP liners reached equilibrium after 7–8 days and remained relatively stable throughout the remaining storage period regardless of cultivar and type of MAP liners (Fig. 1). However, each liner and cultivar set resulted in a specific equilibrium O₂ and CO₂ combination. The equilibrium O₂ and CO₂ combinations for 'Lapins' were: MAP1 (13.4%, 6.5%), MAP2 (7.5%, 8.5%), and MAP3 (1.1%, 10.1%), respectively. The combinations for 'Skeena' were MAP1 (12.1%, 7.3%), MAP2 (6.5%, 9.3%), and MAP3 (0.8%, 11.2%), respectively. Gas compositions in the macro-perforated liners (control) were similar to ambient atmosphere.

3.2. Effect of MAP on fruit respiration and redox status

All the MAP treatments reduced the respiration rate of both cultivars after 4 or 6 week storage (Fig. 2A&B). In comparison with the control, MAP1, 2 and 3 reduced respiration rate by 6.8, 18.6, and 23.7% for 'Lapins'; and 7.7, 20.0, and 33.8% for 'Skeena', respectively, at week 6. AsA content declined rapidly in the control fruit and lost 35 and 53% of the initial content for 'Lapins' and 29 and 52% for 'Skeena' after 4 and 6 weeks, respectively. MAP 2 and 3 slowed down the loss of AsA significantly ($P < 0.05$) compared to the control with no difference between the two MAP regardless of

storage time and cultivar (Fig. 2C&D). After 6 weeks, 'Lapins' and 'Skeena' fruit in MAP2, for example, lost 24% and 28% of the initial AsA concentration, therefore 29% and 24% less than the losses in controls, respectively. MDA content increased 1.5 and 1.4 fold in control for 'Lapins' and 'Skeena', respectively, after 6 weeks (Fig. 2E&F). MAP2 and 3 significantly ($P < 0.05$) reduced the increase of MDA content for both cultivars at both evaluation times. MAP1 did not affect the decline of AsA and the accumulation of MDA ($P < 0.05$) in either cultivar.

3.3. Effect of MAP on fruit quality

3.3.1. SSC and TA

While SSC did not change ($P < 0.05$) (data not shown), TA content decreased in both cultivars during storage at 0 °C (Fig. 3A&B). MAP2 and 3 maintained a higher TA than control in both cultivars at 4 and 6 weeks. In contrast, MAP1 did not affect TA reduction compared to control fruit ($P < 0.05$). After 6 weeks, TA had declined by 25.3, 24.6, 20.5, and 16.1% for 'Lapins' and 26.6, 25.9, 18.6, and 15.2% for 'Skeena' in control and MAP1, 2, and 3 treatments, respectively.

3.3.2. Ethanol

There was minimum amount of ethanol detected (i.e., <1.1 mg kg⁻¹) in the control fruit of 'Lapins' and 'Skeena' during 4 weeks at 0 °C (Fig. 3C&D). At week 4, ethanol concentration was 2.3–16.6 mg kg⁻¹ and 35.6–49.0 mg kg⁻¹ in 'Lapins' and 'Skeena', respectively, packed in MAP1 and 2 with no significant difference ($P < 0.05$) between MAP 1 and 2 for either cultivar. However, fruit in MAP3 accumulated a significant amount of ethanol: 566.7 mg kg⁻¹ and 1263.6 mg kg⁻¹ in 'Lapins' and 'Skeena', respectively.

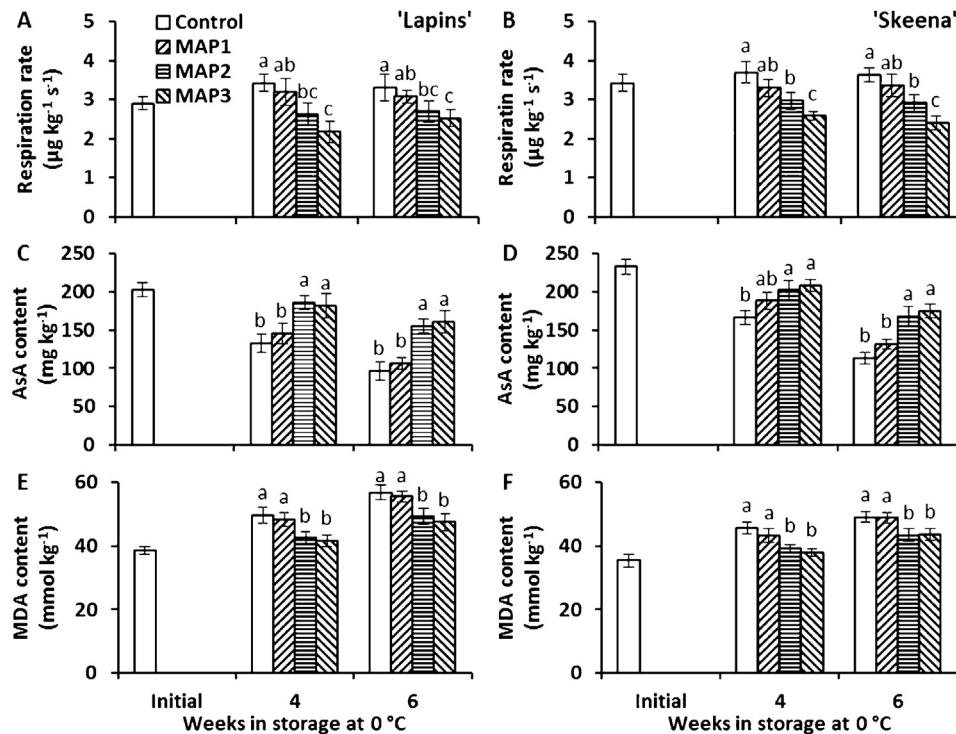


Fig. 2. Effects of 3 different modified atmosphere packaging liners (MAP1–3) and a macro-perforated polyethylene liner (control) on respiration rate, ascorbic acid (AsA), and malondialdehyde (MDA) of 'Lapins' and 'Skeena' cherries after 4 and 6 weeks at 0 °C. Vertical bars represent standard deviations. Different letters indicate significant differences between treatments according to Fisher's protected LSD test at $P < 0.05$.

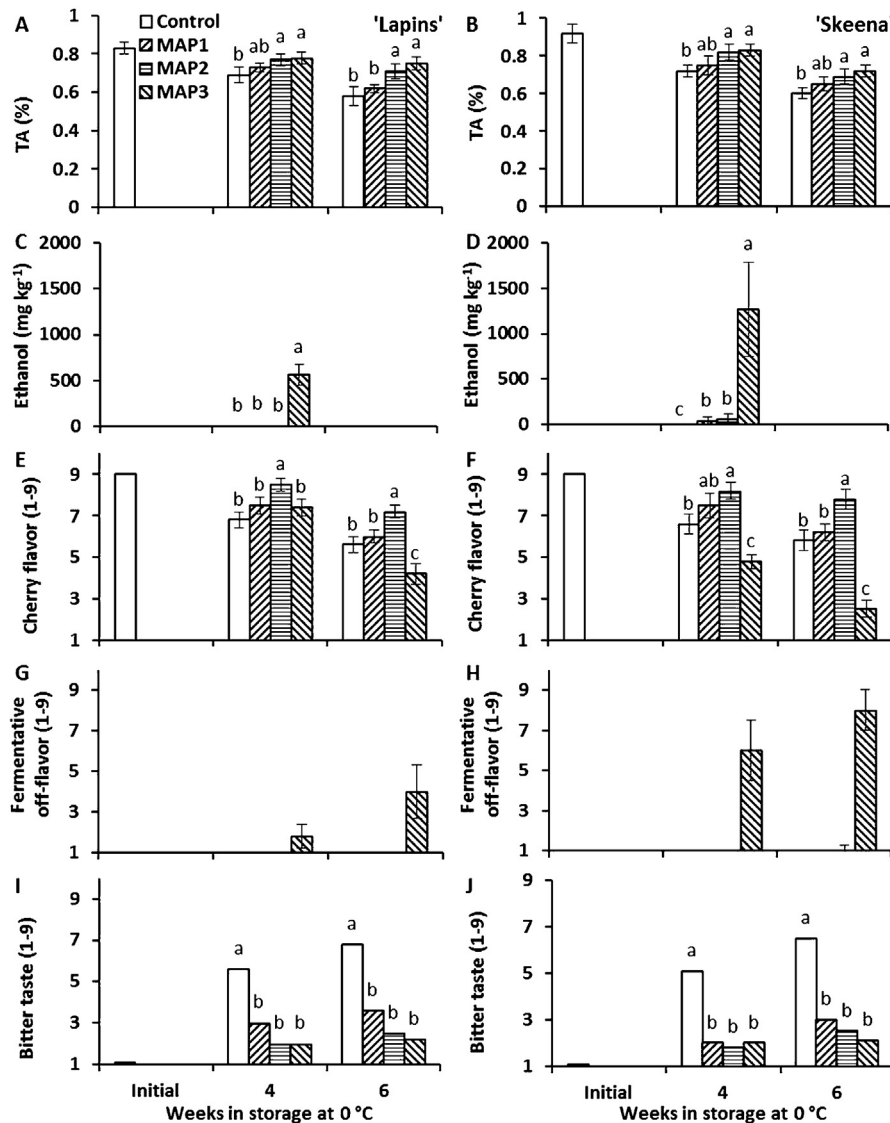


Fig. 3. Effects of 3 different modified atmosphere packaging liners (MAP1–3) and a macro-perforated polyethylene liner (control) on titratable acidity (TA), ethanol content, cherry flavor, fermentative off-flavor, and bitter taste of ‘Lapins’ and ‘Skeena’ cherries after 4 and 6 weeks at 0 °C. Vertical bars represent standard deviations. Different letters indicate significant differences between treatments according to Fisher’s protected LSD test at $P < 0.05$.

3.3.3. Sensory flavor

Fruit in MAP2 had a higher score on cherry flavor for both ‘Lapins’ and ‘Skeena’ compared to MAP1, 3 and control after 4 and 6 weeks at 0 °C (Fig. 3E&F). A fermentative off-flavor was recorded on fruit packed in MAP3 but not in MAP1 and 2 for both cultivars after 4 and 6 weeks (Fig. 3G&H). ‘Lapins’ had lower scores for the fermentative off-flavor than ‘Skeena’ at each evaluation time. A bitter taste was identified in both cultivars after 4 and 6 weeks but all 3 MAP treatments significantly reduced the bitter taste sensation compared to the control in each of the evaluation times (Fig. 3I&J).

3.3.4. Skin color

L^* value in both cultivars declined in storage at 0 °C. While all the MAP treatments retarded L^* decline, MAP2 and 3 maintained the highest L^* values for both cultivars during storage (Fig. 4A&B). Accordingly, anthocyanin content in both cultivars increased during storage. Its accumulation was retarded by all the MAP treatments and fruit in MAP2 and 3 had the lowest anthocyanin contents (Fig. 4C&D). After 6 weeks, the anthocyanin concentration

was 42, 31, 25, and 17% (‘Lapins’) and 27, 25, 14, and 11% (‘Skeena’) higher than at harvest for control and MAP1, 2, and 3, respectively.

3.3.5. Texture

FF of both cultivars increased with no difference among MAP treatments and control after 4 or 6 weeks at 0 °C (Fig. 4E&F).

3.4. Effect of MAP on postharvest disorders

MAP liners did not influence the incidences of pitting and splitting of either cultivar after storage (Table 1). Compared to control, all the MAP treatments reduced pedicel browning and decay incidences but with no significant differences ($P < 0.05$) among the MAP liners after 6 weeks (Table 1).

4. Discussion

Since there was no difference in weight loss among MAP and control, any changes in physiological attributes and fruit quality caused by MAP should be primarily attributed to the modified atmospheres.

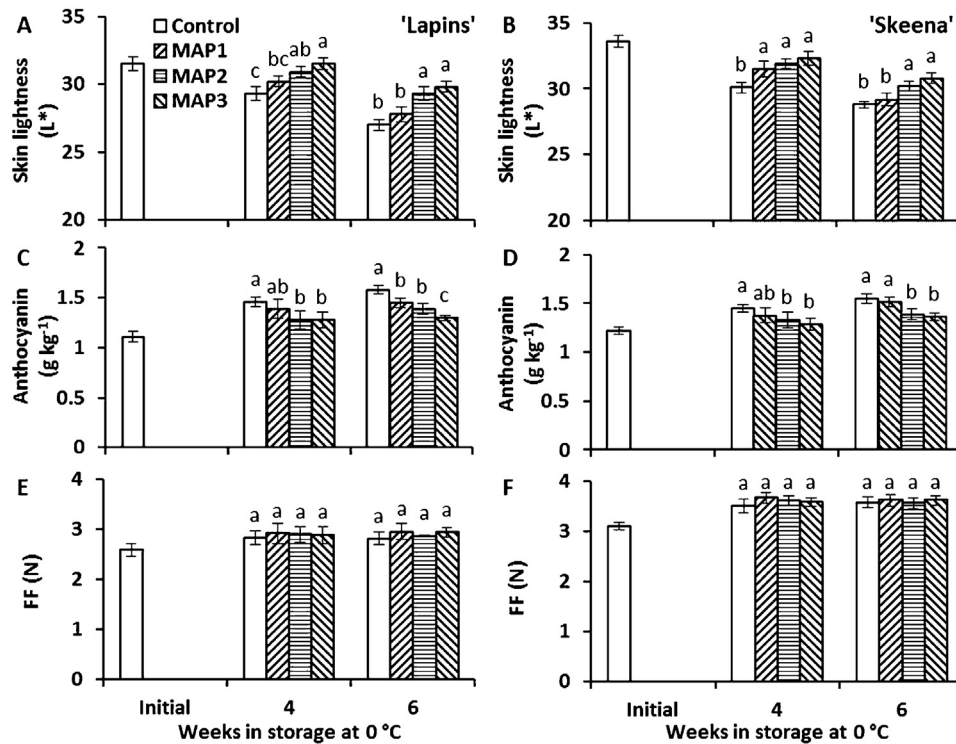


Fig. 4. Effects of 3 different modified atmosphere packaging liners (MAP1–3) and a macro-perforated polyethylene liner (control) on fruit skin lightness (L^*), anthocyanin content, and fruit firmness (FF) of 'Lapins' and 'Skeena' cherries after 4 or 6 weeks at 0°C . Vertical bars represent standard deviations. Different letters indicate significant differences between treatments according to Fisher's protected LSD test at $P < 0.05$.

Table 1

Effects of 3 different modified atmosphere packaging liners (MAP1–3) and a macro-perforated polyethylene liner (control) on postharvest disorders of 'Lapins' and 'Skeena' cherries after 4 or 6 weeks at 0°C . Different letters indicate significant differences between treatments according to Fisher's protected LSD test at $P < 0.05$.

	4 weeks at 0°C				6 weeks at 0°C			
	Pitting (%)	Splitting (%)	Decay (%)	Pedicle browning (%)	Pitting (%)	Splitting (%)	Decay (%)	Pedicle browning (%)
'Lapins'								
Control	12.5a	1.2a	5.8a	37.0a	11.6a	1.5a	10.2a	44.6a
MAP1	11.3a	0.9a	3.5b	26.0b	18.6a	2.1a	4.8b	36.5b
MAP2	12.8a	0.8a	2.6b	25.9b	13.2a	1.3a	3.3b	31.3b
MAP3	10.6a	1.1a	3.1b	25.1b	13.0a	0.8a	4.5b	32.1b
'Skeena'								
Control	5.5a	5.5a	6.3a	11.5a	5.6a	7.5a	9.7a	15.9a
MAP1	7.3a	6.1a	2.0b	8.2b	7.7a	8.9a	2.3b	9.6b
MAP2	6.6a	5.5a	0.5b	6.3b	7.9a	6.8a	3.1b	7.0b
MAP3	9.2a	5.2a	1.3b	5.1b	6.6a	7.6a	4.7b	6.3b

One of the major postharvest quality declines in sweet cherries during long-term storage/shipping is the loss of their characteristic flavor resulting in a bland taste. Sweet cherry flavor is largely determined by a balance between sugar and acid content (Crisosto et al., 2003; Kappel et al., 1996) with little effect by volatile compounds (Mattheis et al., 1997; Meheriuk et al., 1995, 1997). In this study, SSC did not change but TA content decreased significantly in 'Lapins' and 'Skeena' during cold storage. Therefore, the flavor loss in these cultivars is mainly due to a decline in fruit acid content, which is in agreement with the findings in other cherry cultivars (Mattheis et al., 1997; Meheriuk et al., 1995, 1997). This study indicates that MAP with appropriate gas compositions such as MAP2 with O_2 6.5–7.5% + CO_2 8.0–10.0% can slow down TA loss and therefore maintain characteristic cherry flavor of the late season cultivars for 4–6 weeks at 0°C . The result is in agreement with the report of Meheriuk et al., (1997) in that the storage life of 'Sweetheart' cherries was extended up to 4 weeks in O_2 4.6% + CO_2

10% or O_2 6.6% + CO_2 3.5% at 0°C . In contrast, MAP1 having higher gas permeability with O_2 12.0–13.5% + CO_2 5.0–7.0% had little effect on TA loss, which is consistent with MAP with O_2 9–10% + CO_2 7–8% which did not retard TA loss of 'Lapins' at 3°C (Padilla-Zakour et al., 2004). On the other hand, MAP3 with O_2 0.5–1.5% + CO_2 ~10% O_2 maintained higher TA but generated fermentative off-flavor after 4 and 6 weeks in 'Lapins' and 'Skeena'. Meheriuk et al., (1997) reported that 'Lapins' in 0.8% O_2 + 4.5% CO_2 accumulated ethanol after 6 weeks but the fermentative off-flavor was detected after 8 weeks at 0°C .

The reduction in TA loss by MAP 2 and 3 most likely resulted from the decreased fruit respiration rate. It was reported that the sweet cherry TA content had a negative correlation with respiration rate during cold storage (Wang and Long, 2014; Wei et al., 2011), and low O_2 and high CO_2 retarded respiration rate and TA loss (Harb et al., 2003). In contrast, MAP1 did not slow the respiration rate and TA reduction, therefore, had no effect on flavor

loss. The inferior flavor in MAP3 was due to a fermentative off-flavor, which is related to a significant accumulation of ethanol. 'Skeena' synthesized a higher content of ethanol in MAP3 and developed more intensive fermentative off-flavor than 'Lapins'. A significant increase in ethanol concentration in fruit during storage indicates the occurrence of anaerobic respiration (Kays and Paul, 2004). Ethanol concentration in 'Bing' cherry was found to be very low in control and increased in CA (O₂ 5%+CO₂ 15%) storage (Mattheis et al., 1997). Bai et al., (2011) reported 'Lapins' cherry produced a minimum amount of ethanol (i.e., < 2 mg kg⁻¹) during air storage at 1 °C. In this study, ethanol was detected at 2.3 to 49 mg kg⁻¹ in 'Lapins' and 'Skeena' packed in MAP1 and 2 after 4 week storage, however, the panelists did not detect fermentative off-flavor indicating the accumulation of ethanol in the fruit flesh was lower than the human sensory detection threshold. The human olfactory detection threshold for ethanol is 100 mg kg⁻¹ in water (Flath et al., 1967) and 64–900 mg kg⁻¹ in orange fruit (Moshonas et al., 1991). A bitter taste was identified in this study for both 'Lapins' and 'Skeena' after 4 and 6 weeks with control but reduced by all three MAPs. Harb et al., (2006) reported a bitter taste in 'Regina' sweet cherry after 6 weeks of cold storage and MAP could prevent it. Bitter taste development in the late-maturing cultivars during storage/shipping warrants further study.

Sweet cherry fruit color is one of the most important factors influencing consumer purchase decisions (Crisosto et al., 2003). Although consumers prefer dark fruit in cultivars such as 'Lapins' and 'Skeena' harvested at an appropriate maturity (Long et al., 2007), darkening during postharvest gives the fruit a dull and over-ripe appearance that affects consumer preference. Fruit skin darkening during storage/shipping was reflected by lower brightness (L*) (Meheriuk et al., 1995, 1997). This study indicates that MAP retarded anthocyanin accumulation and slowed down the reduction of L* values in 'Lapins' and 'Skeena' during cold storage with higher efficacy in MAP2 and 3 than MAP1. It has been reported that high CO₂ and/or low O₂ retarded cherry fruit darkening in different cultivars during cold storage (Harb et al., 2003; Mattheis and Reed, 1994; Remón et al., 2000, 2004) and the reduction in skin brightness was related to the accumulation of anthocyanin in various sweet cherry cultivars during air storage (Goncalves et al., 2007).

Texture is an important quality attribute in cherries that affects consumer acceptance and FF measured by a FirmTech instrument was highly correlated with just-about-right (JAR) ratings for whole cherry texture (Hampson et al., 2014). FF in 'Lapins' and 'Skeena' was found in this study to increase but within the acceptable firmness range between 2.5 and 4.7 N (Hampson et al., 2014) after 4 and 6 week storage regardless of the MAP treatments. An increase in cherry FF in air, MAP, or CA storage has been reported by others for different cultivars (Chen et al., 1981; Kappel et al., 2002; Remón et al., 2000). However, cherry FF increasing or decreasing during cold storage is a function of cultivars (Toivonen and Kappel, 2012). Bai et al., (2011) reported 'Bing' cherry FF decreased during storage at 1 °C. Factors determining cherry firmness development during storage/shipping warrant further research.

AsA is important not only for human health (Davey et al., 2000), but also for acting as an antioxidant to maintain cell membrane integrity in fruit (Hodges et al., 1999). In 'Lapins' and 'Skeena', AsA content declined and MDA (an indicator of lipid peroxidation) increased during cold storage. Oxidative stress occurs when production of reactive oxygen species (ROS), including superoxide (O₂^{•-}), singlet oxygen (¹O₂), hydrogen peroxide (H₂O₂), and more toxic hydroxyl radical (OH[•]), exceeds the ability of the fruit scavenging system to remove them. Active antioxidant systems can remove ROS and therefore play a crucial role in delaying senescence of fruit (Shewfelt and del Rosario, 2000). While both enzymatic and non-enzymatic antioxidants are implicated in

oxidative stress responses, the non-enzymatic antioxidant AsA plays an important role in detoxification of ROS (Shewfelt and del Rosario, 2000). In sweet cherry, the reduction of AsA degradation by MAP2 and 3 may have resulted in reduced lipid peroxidation as indicated by a reduced accumulation of MDA. This finding that MAP with proper gas combinations retards AsA degradation and MDA accumulation in sweet cherries is consistent with the reports of Harb et al., (2006) and Tian et al., (2004).

Pedicle browning and decay were reduced by MAP with no difference among the three MAP liners. Chen et al., (1981) reported low O₂ maintained a higher percentage of green pedicels in 'Bing' cherries in cold storage. Cherry pedicle browning is a result of the loss of membrane integrity which allows polyphenol oxidase and polyphenol substances to mix in the damaged cells resulting in tissue browning (Schick & Toivonen, 2002). Therefore, the effect of low O₂ on pedicle quality within MAP appears to be due to maintaining cellular integrity. Three decay pathogens were found in this research: *Monilinia fructicola*, *Botrytis cinerea*, and *Rhizopus stolonifera*. High CO₂ (5–20%) in MAP was reported to slow decay pathogen growth on sweet cherries (DeVries-Patterson et al., 1991; Kupferman and Sanderson, 2001). Pitting and splitting were not affected by the three MAP liners tested.

5. Conclusions

AsA degraded rapidly in 'Lapins' and 'Skeena' during storage/shipping, which was related to a corresponding increase in lipid peroxidation and fruit senescence. The senescent process was accompanied with flavor loss and fruit skin darkening. The loss of flavor was mainly due to a decline in fruit acid content and formation of bitter taste. Fruit skin darkening during storage was positively correlated to anthocyanin accumulation. The results of this study showed that MAP liners with the most appropriate gas permeability (such as MAP2) slowed down fruit senescence by retarding AsA degradation and lipid peroxidation, reduced flavor loss by reducing acid loss and bitter taste formation, maintained brighter skin color, and reduced decay and pedicle browning of 'Lapins' and 'Skeena' during cold storage/shipping. Numerous MAP options with varied gas permeability are commercially available for sweet cherries. While those MAP liners with equilibrium O₂ > ~10% may have little effect on retarding fruit senescence, those with equilibrium O₂ < ~1% will cause anaerobic respiration and generate an off-flavor due to the accumulating of ethanol in the late-maturing cultivars. Often temperature fluctuations during shipping will affect the respiratory activity of cherries, and therefore may change O₂ and CO₂ concentrations in MAP. The MAP liners with gas permeability similar to MAP2 may be optimum for commercial shipping of the late season sweet cherries to maintain fruit flavor and bright skin color while avoiding anaerobic injury even at situations with minimum temperature fluctuations.

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