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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 (O_2 6.5–7.5%, CO_2 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 (O_2 12.0–13.5%, CO_2 5.0–7.0%) had little benefit on maintaining fruit flavor and skin color. MAP3 (O_2 0.5–1.5%, $CO_2 \sim 10\%$), 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 O_2 6.5–7.5% and CO_2 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.

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 O_2 and/or increased CO_2 concentrations and a high relative humidity surrounding the

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commodity. The steady state O_2 and CO_2 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 O_2 concentration decreases to the "extinction point", a point that will not sustain aerobic respiration, or CO_2 injury if the CO_2 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 CO_2 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 permeabilites. 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 O_2 0.8% + CO_2 4.5% at 0 °C (Meheriuk et al., 1995) and 4 weeks in O_2 9–10% + CO_2 7–8% at 3 °C (Padilla-Zakour et al., 2004). 'Sweetheart' cherries have a storage life of 4 weeks in O_2 4.6% + CO_2 10% or O_2 6.6% + CO_2 3.5% at 0 °C (Meheriuk et al., 1997). The optimum O_2 and CO_2 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 O_2 and CO_2 in the liners were determined using an O_2/CO_2 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 CO_2 concentrations were determined using a CO_2 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 $\mu g\,kg^{-1}\,s^{-1}$.

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) $HClO_4$. 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 Na_2CO_3. 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 $mmol\,kg^{-1}$.