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Respiration and quality responses of sweet cherry to different atmospheres during cold storage and shipping

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ABSTRACT

Most sweet cherries produced in the US Pacific Northwest and shipped to distant markets are often in storage and transit for over 3 weeks. The objectives of this research were to study the effects of sweet cherry storage O_2 and CO_2 concentrations on the respiratory physiology and the efficacy of modified atmosphere packaging (MAP) on extending shelf life. Oxygen depletion and CO_2 formation by 'Bing' and 'Sweetheart' cherry fruit were measured. While respiration rate was inhibited linearly by reduced O_2 concentration from 21% to 3–4% at 20 °C, it was affected very little from 21% to ∼10% but declined logarithmically from ∼10% to ∼1% at 0 °C. Estimated fermentation induction points determined by a specific increased respiratory quotient were less than 1% and 3–4% O_2 for both cultivars at 0 and 20 °C, respectively. 'Bing' and 'Sweetheart' cherry fruits were packaged (∼8 kg/box) in 5 different commercial MAP box liners and a standard macro-perforated polyethylene box liner (as control) and stored at 0 °C for 6 weeks. MAP liners that equilibrated with atmospheres of 1.8–8.0% O_2 + 7.3–10.3% CO_2 reduced fruit respiration rate, maintained higher titratable acidity (TA) and flavor compared to control fruit after 4 and 6 weeks of cold storage. In contrast, MAP liners that equilibrated with atmospheres of 9.9–14.4% O_2 + 5.7–12.9% CO_2 had little effect on inhibiting respiration rate and TA loss and maintaining flavor during cold storage. All five MAP liners maintained higher fruit firmness (FF) compared to control fruit after 6 weeks of cold storage. In conclusion, storage atmospheres of 1.8–14.4% O_2 + 5.7–12.9% CO_2 generated by commercial MAP, maintained higher FF, but only the MAP with lower O_2 permeability (i.e., equilibrated at 1.8–8.0% O_2) maintained flavor of sweet cherries compared to the standard macro-perforated liners at 0 °C. MAP with appropriate gas permeability (i.e., equilibrated at 5–8% O_2 at 0 °C) may be suitable for commercial application to maintain flavor without damaging the fruit through fermentation, even if temperature fluctuations, common in commercial storage and shipping, do occur.

1. Introduction

Due to a high respiratory activity, minimal reserve carbohydrate, and high susceptibility to mechanical damage, sweet cherries (*Prunus avium* L.) are highly perishable and have a shelf life of only about 2 weeks under cold chain management that includes rapid elimination of field heat after harvest and low temperature control during storage and shipping (Kupferman and Sanderson, 2001). Their shelf life is often shortened due to loss of flavor, darkening of fruit skin color, pedicel browning, and decay development (industry communication).

The combination of controlled atmosphere (CA) with low temperature could be used to further extend storage and shipping life of sweet cherries (Kader, 1997). High levels of CO_2 (10 or 20%) help to reduce decay and retain firmness, acidity, and fruit color (Chen et al., 1981; Patterson, 1982). Low O_2 (0.5–2%) also maintained fruit firmness, brighter color, higher acidity and green pedicels in 'Bing' cherries stored at −1.1 °C (Chen et al., 1981). The storage life of 'Sweetheart' cherries was extended to 6 weeks at 1 °C under CA conditions (5% O_2 and 2% CO_2) and the fruit maintained higher acidity and firmness and brighter color (Remón et al., 2003). In general, O_2 at 3–10% delayed fruit softening and CO_2 at 10–20% limited decay and maintained flesh appearance (Crisosto et al., 2009). However, O_2 concentrations below 1% may induce skin pitting and off-flavor while CO_2 higher than 30% has been associated with brown skin discoloration of 'Bing' cherries (Kader, 1997).

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Previous studies have examined the potential of modified atmosphere packaging (MAP) for extending storage and shipping life of sweet cherries with promising results. Meheriuk et al. (1995, 1997) reported a postharvest storage life of 6 weeks for 'Lapins' cherries with equilibrium atmospheres of 0.8% O_2 + 4.5% CO_2 and 4 weeks for 'Sweetheart' cherries with atmospheres of 4.6–6.6% O_2 + 3.5–10% CO_2 when stored in consumer sized polyethylene bags (500–750 g). MAP box liners effectively maintained better acidity, firmness, color, and stem quality of 'Bing' cherries in cold storage (Crisosto et al., 2009; Lurie and Aharoni, 1997; Mattheis and Reed, 1994). Storage quality of 'Hedelfingen' and 'Lapins' cherries was improved by using MAP box liners that had equilibrated atmospheres of 4–5% O_2 + 7–8% CO_2 and 9–10% O_2 + 7–8% CO_2, respectively (Padilla-Zakour et al., 2004). MAP box liners with equilibrated atmospheres of 1–3% O_2 + 9–12% CO_2 prolonged storage life of 'Burlat' cherries (Remón et al., 2000). The storage life of 'Regina' cherries packed in MAP liners was extended to 5 weeks with improved fruit firmness, skin color, ascorbic acid content, and flavor (Harb et al., 2006). While storage life of some cultivars could be prolonged, the flavor, texture and stem quality of others may be negatively affected by the same MAP box liners (Kahlke et al., 2009) indicating that package selection is highly cultivar dependent. Petracek et al. (2002) found that modified O_2 and CO_2 in MAP atmospheres had no apparent benefit to the shelf life of 'Sam' sweet cherries with respect to respiration and mold control.

More than 1/3 of US Pacific Northwest (PNW) sweet cherries are exported each year. Most of the cherries are shipped to distant markets with storage and transit often requiring over 3 weeks (industry communication). Extending storage and shipping life and assuring good arrival quality of sweet cherries are requisites for satisfying consumers and keeping the PNW cherry industry profitable. Commercial use of MAP for cherries has developed rapidly in the PNW allowing delivery of cherries to distant markets by boat instead of air freight thereby reducing costs (Kupferman and Sanderson, 2001). A number of box liners with differing gas diffusion rates have become available, however, detailed evaluations under similar conditions are lacking. The altered gas atmosphere surrounding the commodity in MAP is created by the respiration of the product and the polymeric film's resistance to O_2 and CO_2 diffusion (Mir and Beaudry, 2004). A good understanding of product respiration dynamics as affected by cultivar, temperature, O_2 and CO_2 concentrations, maturity, and production environment is essential for optimizing MAP efficacy. Sweet cherries have moderate to high respiration rates (expressed as production rate of CO_2) with significant differences among cultivars (e.g., from 7.2 μg kg^{-1} s^{-1} of 'Hedelfingen' to 36 μg kg^{-1} s^{-1} of 'Emperor Francis' at 20 °C and others in between) reported in the literature (Blanpied, 1972; Crisosto et al., 1993; Sekse, 1988; Toivonen et al., 2004). The influence of O_2 and CO_2 concentrations on respiration rates of PNW cultivars under storage and shipping conditions is poorly understood.

Respiration rate measurements are commonly made as CO_2 evolution in a flow through system (Kays and Paull, 2004). Respiration dynamics, as a function of O_2 and CO_2 concentrations, are most conveniently done in a hermetically sealed chamber in a single experiment (Beveridge and Day, 1991; Jaime et al., 2001). Data collected in sealed chambers has been demonstrated to be adequate for determining the gas compositions inside sealed packages of respiring commodities (Deily and Rizvi, 1981).

The objectives of this study were to (1) assess the effect of O_2 and CO_2 concentrations and temperature on the respiration rate of cherry fruit using a closed system; and (2) evaluate the effects of different gas atmospheres generated by various commercial MAP liners on fruit quality during storage and shipping of the two major cultivars ('Bing' and 'Sweetheart') grown in the PNW (Long et al., 2007).

2. Materials and methods

2.1. Fruit materials

Commercially packed 'Bing' and 'Sweetheart' cherries, 20 boxes (~8 kg/box) of each cultivar (row size 10 = 26.6 mm diameter), were obtained from Orchard View Farms (OVF) (The Dalles, OR) and transported to Mid-Columbia Agricultural Research and Extension Center (Hood River, OR). The fruit were harvested at commercial maturity of color grade 4–5 according to the color comparator developed by CTIFL (Centre Technique Interprofessionnel des Fruit et Legumes, Paris, France), in which 1 – light pink and 7 – dark mahogany. Harvested fruit were hydrocooled and packed (fruit pulp temperature at 0–2 °C) the same day by OVF using standard industry procedures for both cultivars. The respiration experiments and MAP trial described below were started the second day after harvest.

2.2. Closed system respiration experiments

Two boxes of each cultivar were used for respiration experiments. Thirty sound fruit with pedicels were weighed and then placed inside each of the air-tight glass containers (960 mL) equipped with 2 rubber self-sealing sampling ports, and equilibrated at 0, 10, and 20 °C for at least 4 h prior to the experiment. A thin layer of Vaseline® was incorporated into the gap between lid and jar to ensure a hermetic seal for all the containers. To determine the influence of CO_2 on respiration activity, 5 mL of 20% KOH solution in a glass beaker was placed between fruit in selected containers for absorption of CO_2 from the air.

Headspace O_2 and CO_2 concentrations were periodically monitored using an O_2/CO_2 analyzer with an accuracy of ±0.2% (Model 900161, Bridge Analyzers Inc., Alameda, CA, USA). The analyzer was manufactured with a configuration that recirculated headspace gases. The entrance and exit ports of the analyzer were connected to the entrance and exit ports of the glass containers, and therefore the air sample was flowing continuously between the glass container and the analyzer. Headspace sampling was stopped when the O_2 level inside the container reached <0.1%. The rates of O_2 uptake (R_{O_2}) and CO_2 production (R_{CO_2}) and respiratory quotient (RQ) were calculated using Eqs. (1)–(3), respectively,

$$R_{O_2} = dO_2\% \times V_f \div W \div dt \div 100 \quad (1)$$

$$R_{CO_2} = dCO_2\% \times V_f \div W \div d \div 100 \quad (2)$$

$$\mathrm{RQ} = \frac{R_{CO_2}}{R_{O_2}} \quad (3)$$

where V_f is the free volume inside the glass jar (μL), W is the total weight of the product (kg), and time unit is s. R_{O_2}, R_{CO_2}, and RQ were plotted against the decreasing O_2 concentration as a function of holding period.

2.3. MAP trial

Ten fruit were randomly selected from each box of each cultivar (18 boxes/cultivar) for initial quality evaluations of fruit firmness (FF), soluble solid content (SSC), titratable acidity (TA), and sensory quality. The remaining fruit were immediately packed at 0 °C into 5 different MAP liners and a standard macro-perforated polyethylene box liner as the control (~8 kg/box, 3 boxes/liner). The 5 sweet cherry MAP box liners were ViewFresh® (61954, OVF, The Dalles, OR), Xtend® (815-CH57/14, StePac, Tefen, Israel), LifeSpan®