

FINAL PROJECT REPORT**YEAR: 3 of 3 years****Project Title:** Extending storage/shipping life and assuring good arrival of sweet cherry

PI: Yan Wang
Organization: OSU-MCAREC
Telephone: 541-386-2030 ext. 214
Email: yan.wang@oregonstate.edu
Address: 3005 Experiment Station Dr.
City/State/Zip: OR97031

Cooperators: Todd Einhorn, Lynn Long, Xingbin Xie, Jinhe Bai (USDA-ARS), David Felicetti (Pace International LLC), Ryan Durow (Orchard View Farm), Kumar Sellakanthan (Amcor), Ray Clarke (Apio Inc.)

Total Project Request: Year 1: \$26,375 **Year 2:** \$26,913 **Year 3:** \$24,466

Other funding sources: None**WTFRC Collaborative expenses: None****Budget 1: Yan Wang****Organization Name:** OSU-MCAREC**Contract Administrator:** L.J. Koong**Telephone:** 541-737-4066**Email address:** l.j.koong@oregonstate.edu

Item	2012	2013	2014
Salaries		10,384 ¹	10,696 ⁷
Benefits		1,848 ²	1,903 ⁷
Wages	9,600	5,312 ³	5,471 ⁷
Benefits	8,275	1,222 ⁴	1,259 ⁷
Equipment			
Supplies	8,000	7,647 ⁵	4,637
Travel	500	500 ⁶	500
Miscellaneous			
Total	26,375	26,913	24,466

Footnotes:¹Postdoctoral Research Associate (Dr. Xingbin Xie): 550hr at \$18.88/hr.²OPE: \$3.36/hr.³Wages: 390hr for a Biological Science Tech. at \$13.62/hr.⁴OPE: 23% of the wage.⁵Supplies: fruit, Ca and Cl analysis, GC-MS volatile analysis, gases (helium, nitrogen, hydrogen, standard gases), gas tank rental, chemicals, and MCAREC cold room use fee.⁶Travel to grower's fields⁷3% increase

OBJECTIVES

The goal of this project was to minimize pitting, postharvest splitting, acid loss, dull color, and stem browning, therefore improve shipping quality of the PNW and California sweet cherries.

The key objectives were to:

1. **Modified atmosphere packaging (MAP):** Determine the optimum MAP parameters (O_2 , CO_2) and efficacy of the major commercial MAP liners and consumer packaging for improving shipping quality of the PNW and California cultivars.
2. **Calcium (Ca):** Study the mechanism and practical postharvest Ca treatment to minimize pitting and splitting of PNW sweet cherries.
3. Evaluate **edible coatings and GRAS compounds** on shipping quality of PNW sweet cherries.

SIGNIFICANT FINDINGS

1. Respiration physiology influenced by O_2 and CO_2 , temperature, and cultivars

- At shipping temperatures, respiration rates of the major PNW and California cultivars were affected very little by reduced O_2 from 21 to 10%, but declined significantly from 10 to 5%.
- Estimated fermentation induction points were about 1-4% O_2 for the major cultivars depending on temperatures.
- CO_2 at 0-15% did not affect respiration rates of 'Bing', 'Sweetheart', and 'Coral'.
- 'Skeena' had a higher RQ (respiration quotient) and respiration Q_{10} than other cultivars. Therefore, 'Skeena' is more susceptible to anaerobic injury.
- 'Skeena' fruit stressed by heat had a higher respiration rate and are more susceptible to anaerobic injury.

2. MAP Technologies

- It was found that the major commercial MAP liners (7) had extremely varied equilibrium O_2 (i.e., 1-15%) and CO_2 (i.e., 5-13%) concentrations for the major PNW and California cultivars at simulated commercial shipping conditions.
- **O_2 concentration affected flavor.** MAP liners with equilibrium O_2 5-8% at 32 °F reduced respiration rate and therefore maintained titratable acidity (TA) and flavor of the major cultivars after 4-6 weeks of cold storage. MAP liners with $O_2 > 10\%$ did not maintain flavor. MAP liners with $O_2 < 5\%$ may cause anaerobic fermentation during commercial storage/shipping.
- **CO_2 concentration affected fruit color darkening.** MAP liners with equilibrium CO_2 10-15% maintained the shiny fruit color at simulated storage/shipping conditions. MAP liners with $CO_2 < 8\%$ had little beneficial effect on maintaining fruit shiny color.
- '**Regina**', '**Skeena**', and '**Lapins**' produced a bitter taste after 3-6 weeks storage/shipping. MAP liners with O_2 at 5-8% prevented or reduced bitter taste development.
- '**Skeena**' is more susceptible to anaerobic fermentation at fluctuated temperatures, therefore, needs MAP liners with relatively higher gas permeability (i.e., O_2 8-10%) to avoid anaerobic injury in commercial storage/shipping.
- **Consumer packaging.** Zipper-lock bags and clamshells with perforation ratio of 0.5% (3mm diameter) maintained cherry pedicel healthier than the commercial ones (perforation at 2-5%, 8mm diameter), without generating extra condensation or fermentation after a simulated storage/shipping/marketing period.

3. Postharvest Ca application in hydro-cooling water

- Pitting susceptibility was found to be correlated negatively with fruit tissue Ca content.
- Splitting potential was correlated with fruit tissue Ca content and pectin chemistry.
- Adding Ca (0.2-0.5%) in hydro-cooling water (32 °F) efficiently increased fruit tissue Ca content in 5 min.
- The enhanced Ca concentration increased fruit firmness (FF) and retarded fruit senescence, therefore, reduced pitting susceptibility, maintained TA and Vc, and reduced postharvest splitting and decay of ‘Bing’, ‘Skeena’, ‘Lapins’ and ‘Sweetheart’.
- EDTA (a chelator of divalent cation) or low pH (i.e., <4) depleted Ca from fruit and increase splitting of cherry fruit.
- Ca application rate and temperature gradient between fruit and solution were the key factors determining efficacy of the Ca treatments.
- Higher Ca rates (1.0-2.0%) damaged cherry stems.
- Cherry fruit didn’t take up Cl.

4. Edible coatings and GRAS compounds

- Semperfresh™ at appropriate rates (i.e., 0.5% a.i.) reduced moisture loss, maintained stem quality, and reduced pitting expression of cherries packed in clamshells. Semperfresh™ at its label rate of 1.0% a.i. increased pitting expression of ‘Sweetheart’.
- Postharvest applications of salicylic acid (SA) and oxalic acid (OA) tended to reduce respiration rate and maintain higher TA during storage.
- There may be little benefit at commercial level from postharvest applications of Chitosan, Sodium alginate, Jasmonic acid (JA), Methyl Jasmonate (MeJA), ethanol, GA₃, and Homobrassinolide (HBR) on PNW sweet cherries.

METHODS

1. Respiration physiology

Cherry samples of ~500g of ‘Bing’, ‘Skeena’, ‘Regina’, ‘Lapins’, ‘Sweetheart’, and ‘Coral’ were placed in hermetically sealed glass containers (960mL) equipped with 2 rubber sampling ports at 32 and 68°F. Headspace O₂ and CO₂ concentrations were periodically monitored by an O₂/CO₂ analyzer. Respiration rates based on O₂ consumption and CO₂ production, fermentation induction point, and respiration quotient (RQ) were plotted with O₂ and CO₂ concentrations.

2. MAP Trials

The major commercial MAP liners (ViewFresh, Xtend, LifeSpan, Breathway, Primpro, PEAKfresh, FreshLOK) with distinct technologies were obtained from the manufactures. Fruit of different cultivars were either obtained from packinghouses shortly after packing or harvested directly from the field and then packed into different MAP liners after pre-cooling. The concentrations of O₂ and CO₂ in MAP liners were determined every day in the first week then every 3-5 days until at the end of the tests. At 2, 4, and 6 weeks, 50 fruit were randomly selected from each box for determinations of respiration, FF, color, anthocyanin, SSC, TA, Vc, ethanol, and volatile-aroma compounds (GC-MS) immediately after cold storage and plus 2 days at 68°F. Fifty fruit were randomly selected for evaluations of pitting, splitting, stem quality, decay, and sensory evaluation. Experimental units were boxes and there were three replications per treatment at each evaluation period. The experimental design was completely randomized.

3. Postharvest Ca Application in hydro-cooling water

Ca solutions at 0, 0.2, 0.5, 1.0, and 2.0% were cooled to 32 °F before treatments. Fruit harvested at commercial maturity from MCAREC with fruit pulp temperature 70-80 °F were immediately hydro-cooled in the cold Ca solutions for 5 min to simulate the commercial hydro-cooling procedures. Fruit tissue Ca and Cl content (ICP-AES and Lachat Quikchem autoanalyzer methods, respectively),

shipping quality (pitting, splitting), eating quality, nutraceutical values, and biochemical changes were evaluated after 2, 4, and 6 weeks of cold storage.

4. Postharvest Applications of edible coatings and GRAS Compounds

Semperfresh™, Chitosan, Sodium alginate, Salicylic acid (SA), Oxalic acid (OA), Jasmonic acid (JA), Methyl Jasmonate (MeJA), ethanol, GA₃, Homobrassinolide (HBR, a brassinosteroid) are applied postharvest on certain PNW cultivars.

RESULTS AND DISCUSSION

1. Respiration Dynamic

While respiration rate of cherry fruit was inhibited linearly by reduced O₂ concentration from 21% to 3-4% at 68 °F, at 32 °F it was affected very little from 21% to ~10% but declined significantly from ~10% to ~1% for ‘Bing’, ‘Sweetheart’, and ‘Coral’ (Fig. 1). Estimated fermentation induction points determined by a specific increased RQ were ~1% and 3-4% O₂ for all cultivars at 32 and 68 °F, respectively. As a consequence, the gas permeability of MAP has to be modified to reduce O₂ between 10-5% at 32 °F within the package to inhibit cherry fruit respiration activity to maintain fruit quality (flavor) without anaerobic fermentation during commercial storage/shipping.

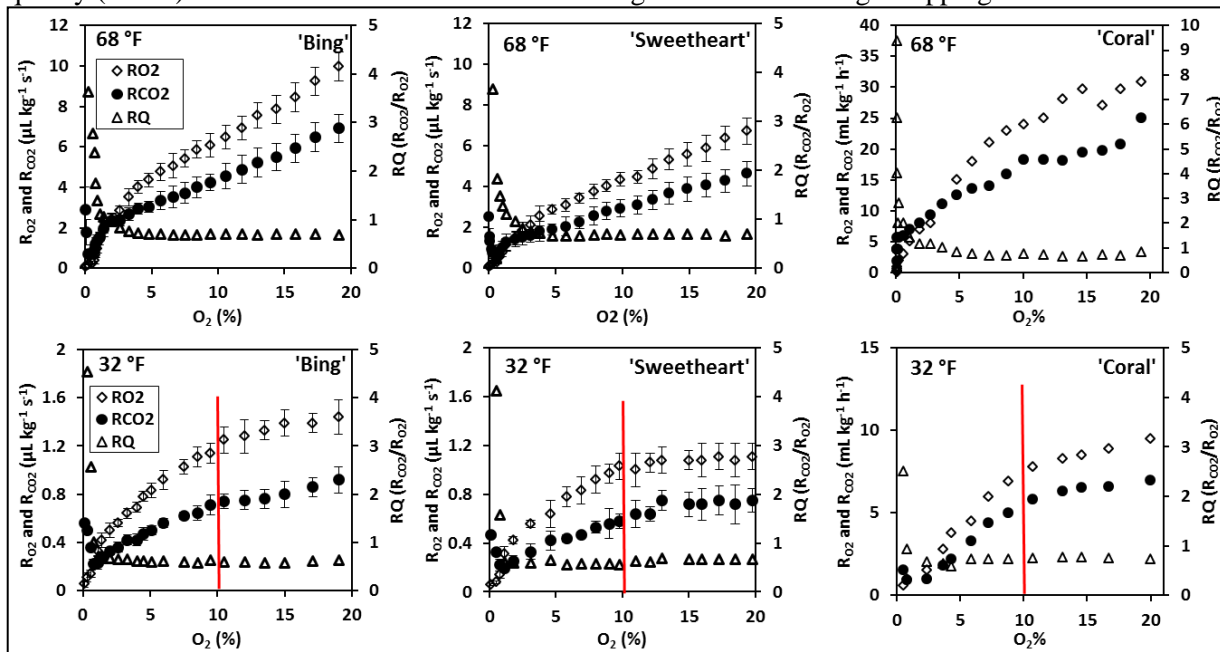


Fig. 1. Respiration dynamics of sweet cherries affected by O₂, temperature, and cultivars.

‘Skeena’ has a higher RQ at elevated temperatures and therefore is more sensitive to anaerobic injury due to temperature fluctuations during shipping (Fig. 2). MAP liners with equilibrium 8-10% O₂ at 32 °F may be suitable for ‘Skeena’ at commercial shipping. Q₁₀ was determined to be 3.5, 3.3, 3.1, and 3.0 at temperatures from 32 to 50 °F for ‘Skeena’, ‘Lapins’, ‘Regina’ and ‘Sweetheart’, respectively. ‘Skeena’ fruit stressed by heat in the field had higher respiration rates, a shorter shelf-life, and were more susceptible to anaerobic injury (Data not shown). Heat stressed Skeena could show pitting on the trees.

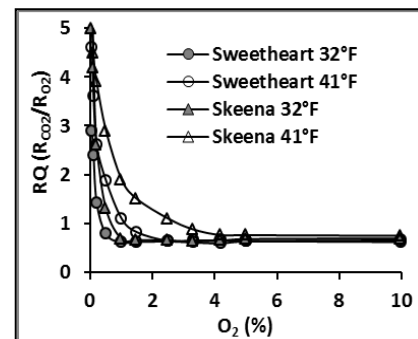


Fig. 2. RQ of Sweetheart and Skeena.

2. MAP Technologies

1) Gas permeability of different MAP liners.

The seven commercial MAP liners used in sweet cherry industry generated extremely varied equilibrium O₂ and CO₂ concentrations for different cultivars at recommended shipping temperatures (Fig. 3). O₂ ranged from 1-15% and CO₂ ranged from 5 to 15% for ‘Bing’, ‘Lapins’, ‘Skeena’, ‘Regina’, ‘Sweetheart’, and ‘Coral’.

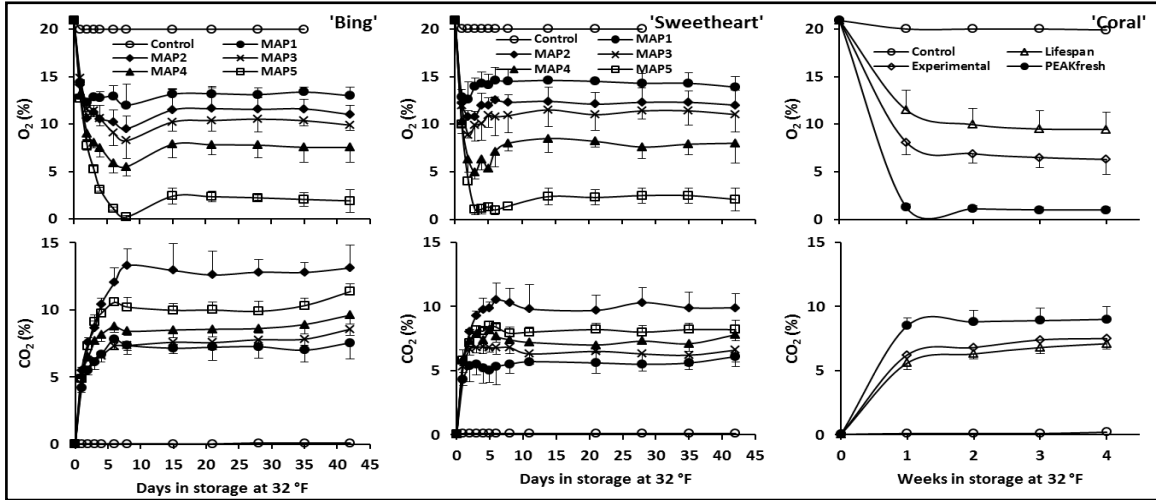


Fig. 3. O₂ and CO₂ contents in different MAP liners for ‘Bing’, ‘Sweetheart’, and ‘Coral’ at 32°F.

2) Effect of elevated temperatures on O₂ and CO₂ in MAP liners and anaerobic fermentation.

Elevated transit temperatures from 32 to 41 °F reduced O₂ significantly (Fig. 4) but did not change CO₂ much in MAP liners. The equilibrium O₂ in MAP4 and MAP5 were reduced from ~6% and 2% at 32 °F to ~3.5% and 0.5% at 41 °F for Sweetheart and Skeena, respectively (Fig. 4). At 36 °F, the equilibrium O₂ was 4.5% and 1% in MAP4 and MAP5 during 2 weeks of cold storage and there was no significant accumulation of ethanol in ‘Sweetheart’ and Skeena after 2 weeks of cold storage (data not shown). At 41 °F, ethanol was accumulated significantly in ‘Sweetheart’ packed in MAP5 and Skeena packed in MAP4 and MAP5 (Fig. 4). Fermentation flavor was detected in the fruit with significant ethanol accumulation. In conclusion, MAP with appropriate gas permeability (i.e., 5-8% O₂ for most of the cultivars and 8-10% O₂ for Skeena) are suitable for commercial application to maintain flavor without damaging the fruit through fermentation, even if temperature fluctuations, common in commercial storage/shipping, do occur.

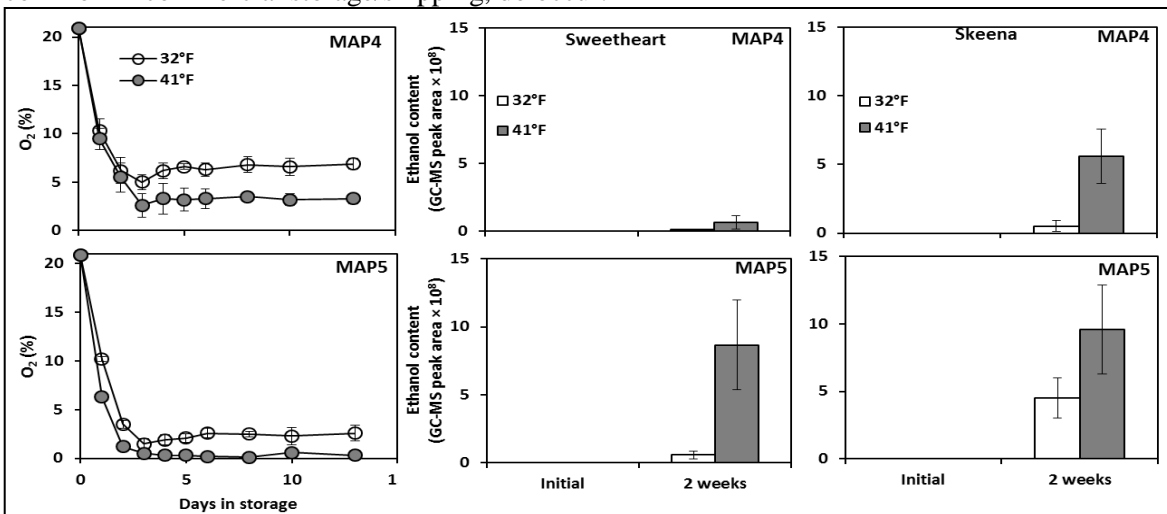


Fig. 4. Effect of elevated temperature on O₂ in MAP and ethanol accumulation in cherry fruit.

3) *Efficacies of different MAP liners on maintaining fruit shipping quality.* While all the MAP liners maintained higher FF and reduced decay, only the MAP liners with lower O₂ permeability (i.e., equilibrated at 5-8% O₂) reduced fruit respiration rate and maintained TA and flavor compared to the standard macro-perforated PE liners after 4-6 weeks of cold storage. In contrast, MAP liners that equilibrated with atmospheres of 10-15% O₂ had little effect on inhibiting respiration rate and TA loss, MAP with 1-2% O₂ enhanced ethanol accumulation and fermentation flavor during cold storage (Fig. 5).

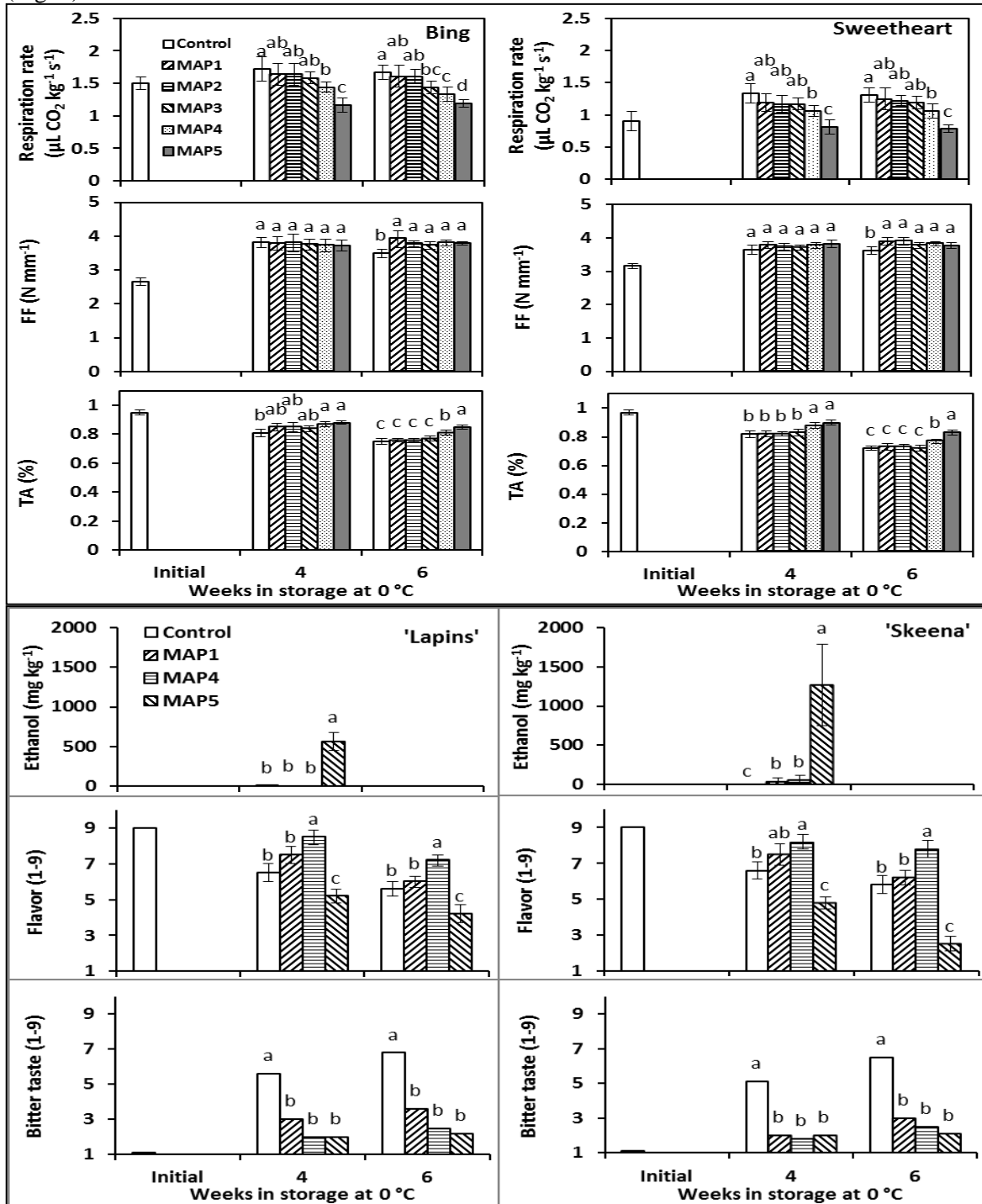


Fig. 5. Effect of MAP on cherry fruit quality during storage.

Cherry fruit skin darkening during storage gave the fruit a dull and over-ripe appearance that affected consumer preference. Fruit skin darkening during storage was reflected by reduced L^* and increased anthocyanin accumulation. Higher CO_2 concentrations (10-15%) in MAP retarded anthocyanin accumulation and fruit skin color darkening significantly. In contrast, $CO_2 < 8\%$ had much less effect on retarding anthocyanin synthesis and maintaining the luster skin color of cherry fruit after cold storage/shipping (Fig. 6).

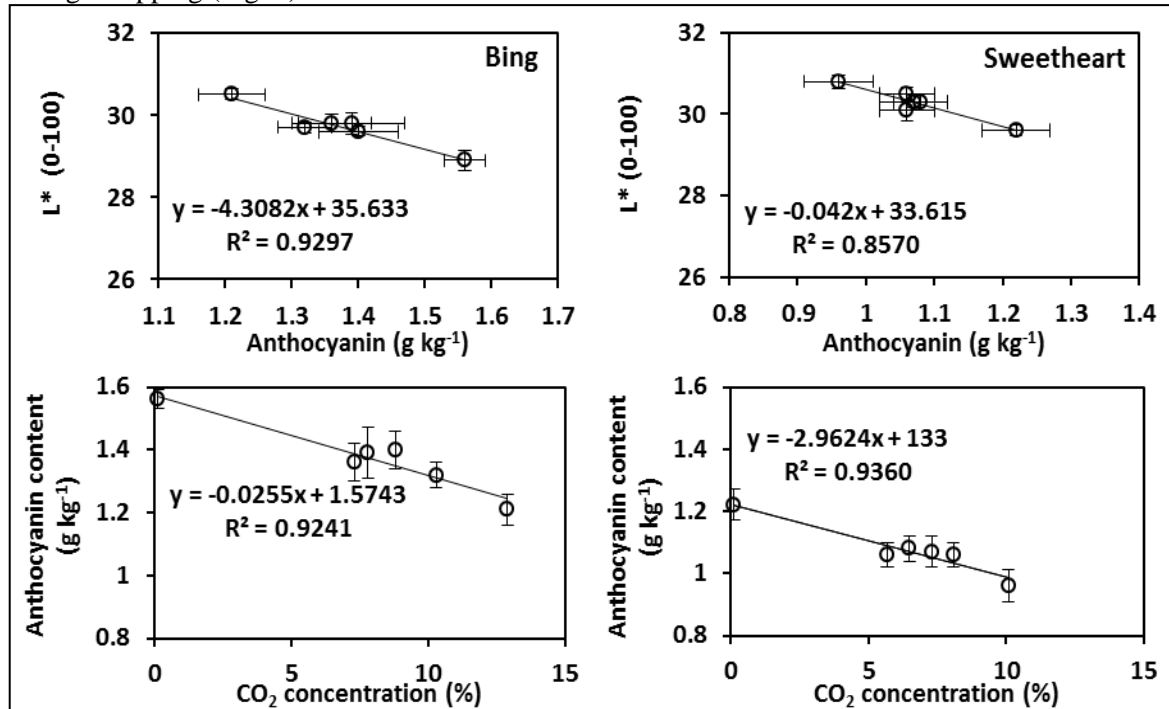


Fig. 6. The relationship of cherry fruit skin darkening with anthocyanin and CO_2 concentration in MAP during storage at 32 °F.

4) Consumer packaging. The perforation ratios of commercial zipper-lock bags or clamshells were ranged from 2-5%. The RH within zipper-lock bags with perforation of 2% were 96%, 93%, and 91% at environment temperatures of 32°F (RH 88%), 50°F (RH 75%), and 68°F (RH 65%), respectively. The RH within zipper-lock bags with perforation of 0.5% were 99%, 98%, and 96% at 32°F, 50°F, and 68°F, respectively. RH within the bags with perforation of 0.05% was close to 100% at each of the temperatures tested (Fig. 7). Stem moisture losses of Chelan and Lapins were higher in bags with 2% perforation than 0.5% and 0.05% at each of the simulated marketing stages. Stem visual quality was higher in bags with perforation at 0.5% than at 2% after 1 week at 32°F + 2 days at 50°F + 2 days at 68°F. Bags with perforation at 0.05% had higher condensation and higher decay incidence (data not shown).

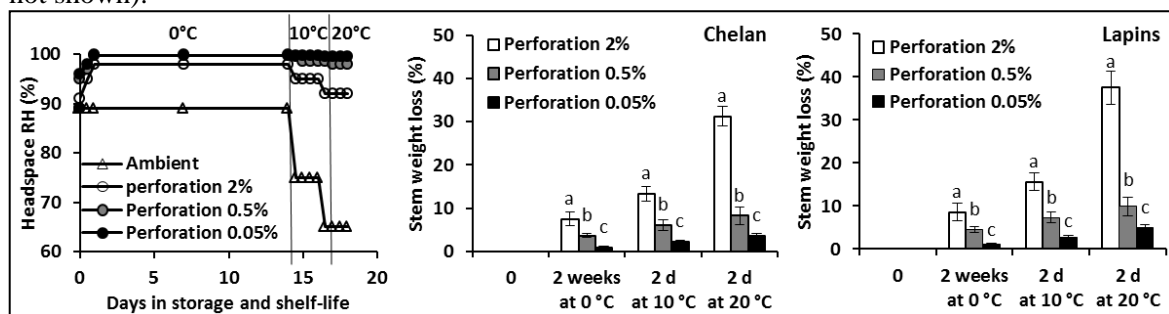


Fig. 7. Effect of perforation ratio in zip-lock bag or clamshell on RH and cherry stem weight loss.

3. Postharvest Ca Application in Hydro-Cooling Water

1) *Increasing fruit tissue Ca content.* Cherry fruit absorbed Ca with increasing Ca concentration from 0.2 to 2.0% in cold water (0 °C) for 5 min (simulating commercial hydro-cooling), but did not take up Cl (Fig. 8). Extending the exposure time from 5 to 30 min increased tissue Ca content of both cultivars at each Ca rate numerically but not at a statistically significant level.

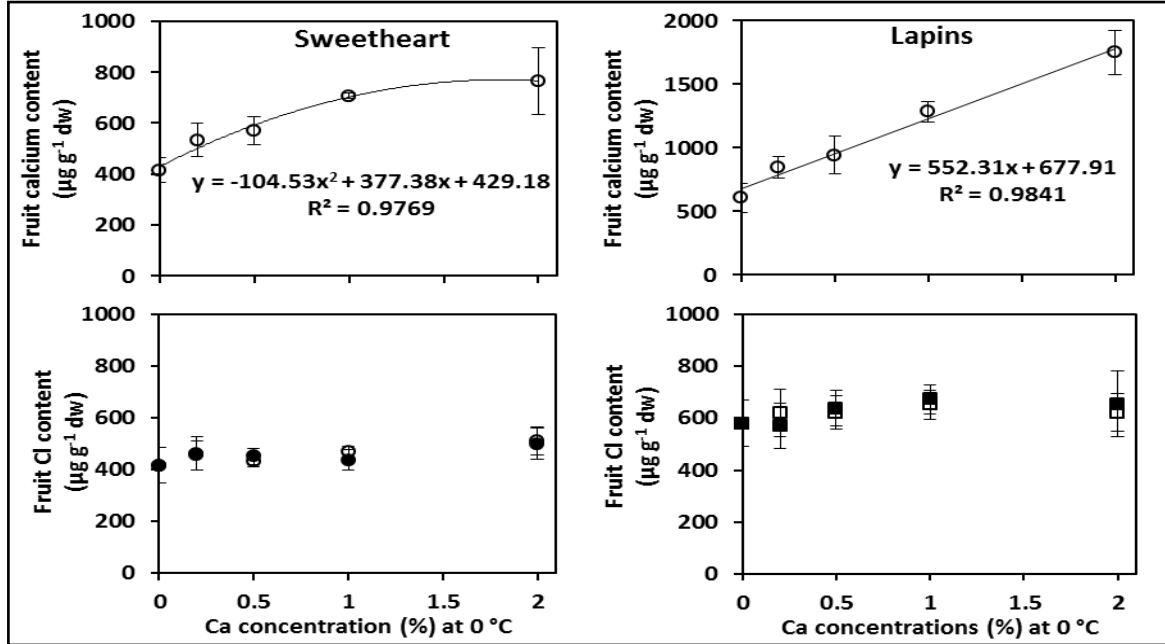


Fig. 8. Tissue Ca and Cl uptakes by cherry fruit as affected by CaCl_2 in cold water at 0 °C.

2) *Retarding senescence, increasing firmness, and reducing pitting.* The increase of fruit tissue Ca content was accompanied by reductions in respiration rate, ascorbic acid (AsA) degradation, and membrane lipid peroxidation (Fig. 9). The Ca treatments enhanced total phenolics content and total antioxidant capacity, and resulted in increases in fruit firmness and pitting resistance (Fig. 10) and decreases in TA loss and decay (data not shown) of both cultivars. Pedicel browning was inhibited by Ca at 0.2% and 0.5%, but increased by higher rates at 1.0% and 2.0% (Fig. 11), possibly via modifying membrane lipid peroxidation.

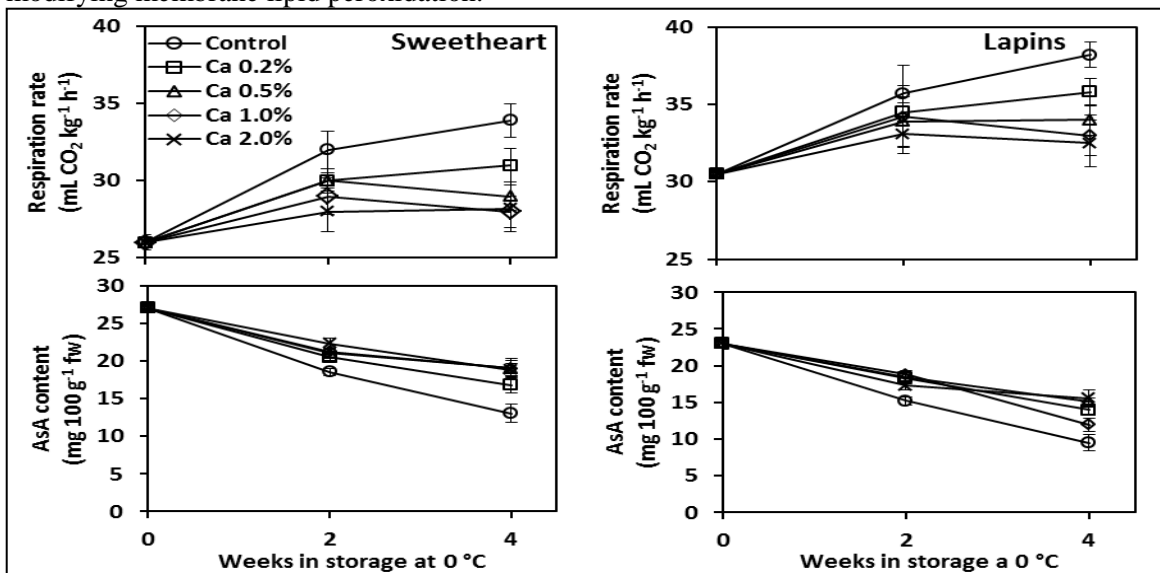


Fig. 9. Effect of Ca in hydro-cooling water on cherry respiration rate and AsA degradation.

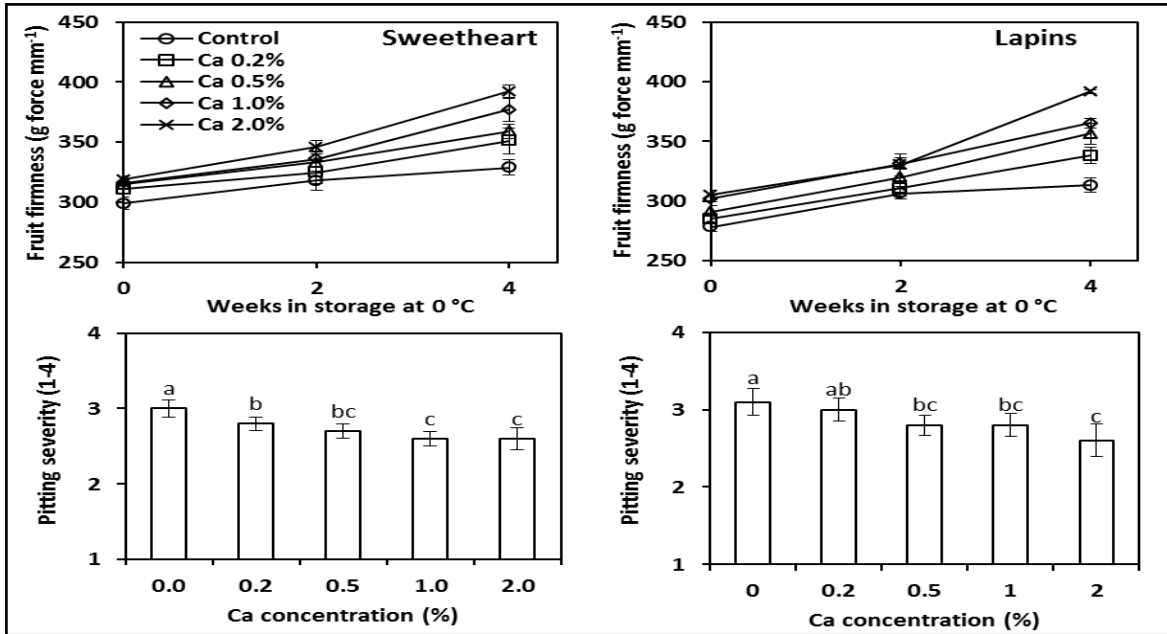


Fig. 10. Effect of Ca in hydro-cooling water on cherry fruit firmness and pitting susceptibility.

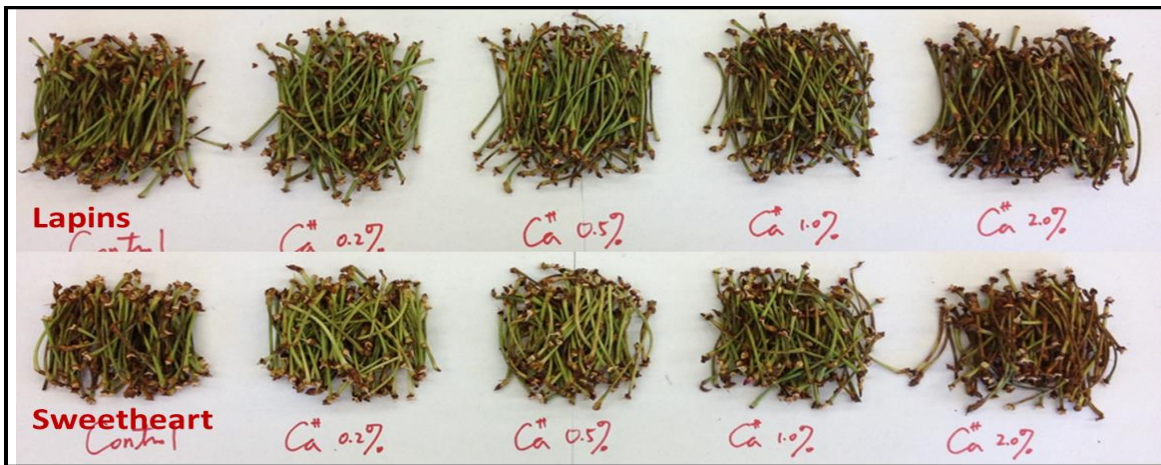


Fig. 11. Effect of Ca in hydro-cooling water on cherry stem quality after 2 weeks of storage.

3) **Reducing splitting of Skeena and Bing.** The enhanced tissue Ca content reduced splitting potential of the splitting-susceptible cultivars (i.e., Skeena) by decreasing fruit soluble pectin release and increasing the splitting threshold. In contrast, depleting Ca from fruit tissue by EDTA or low pH increased soluble pectin release and splitting potential (Fig. 12).

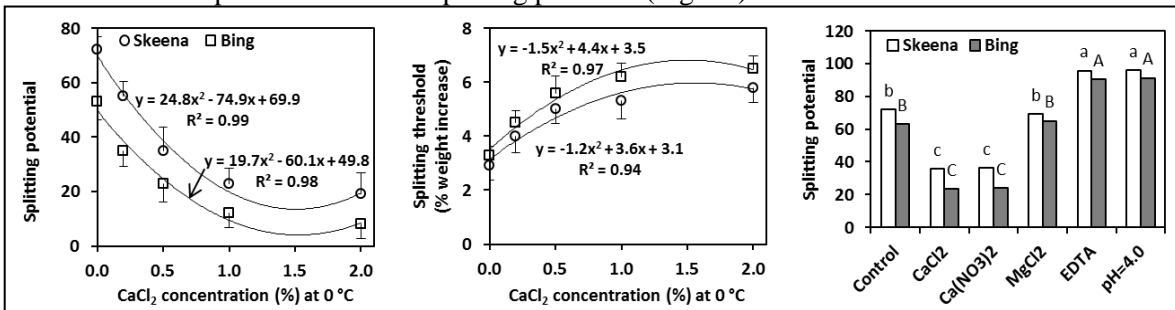


Fig. 12. Effect of Ca in hydro-cooling water on splitting potential of Skeena and Bing cherries.

4. Postharvest Treatments with GRAS Compounds and edible coatings

1) SA, OA, JA, MeJA, ethanol, HBR,

Postharvest applications of SA and OA tended to reduce respiration rate and maintain TA of PNW cultivars packed in clamshells during storage (Fig. 13). It was reported that both SA and OA enhanced total antioxidant capacity (TAC) in ‘Cristilina’ and ‘Prime Giant’ cultivars (Valero et al., 2011), however, they do not seem to affect TAC of PNW cultivars during cold storage (Fig. 13). Postharvest treatment with JA, MeJA, ethanol, and HBR had little effect on shipping quality of ‘Lapins’ and ‘Skeena’ at commercial level (data not shown).

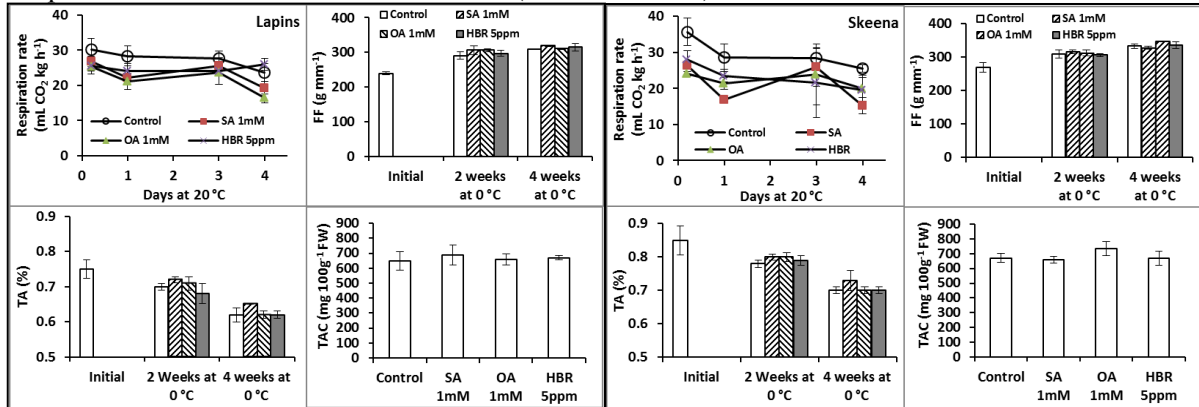


Fig. 13. Effect of SA, OA, and HBR on respiration rates, TA, FF, and total antioxidant capacity (TAC) of ‘Lapins’ and ‘Skeena’.

2) Semperfresh™, GA₃, sodium alginate, chitosan

Semperfresh™ at 0.5% a.i. reduced moisture loss and maintained green stem of ‘Chelan’ and ‘Lapins’ packed in clamshells at simulated marketing conditions (Fig. 14). GA₃ at 100ppm did not affect shipping quality of ‘Chelan’ and ‘Lapins’. Semperfresh™ reduced pitting of ‘sweetheart’ at application rate of 0.5% a.i., but increased pitting at its label rate of 1.0% a.i. (Fig. 15). Pitting formation seems to be associated with moisture loss and localized O₂ deficiency. Chitosan and alginate had little effect on shipping quality of ‘Chelan’ and ‘Lapins’ (data not shown).

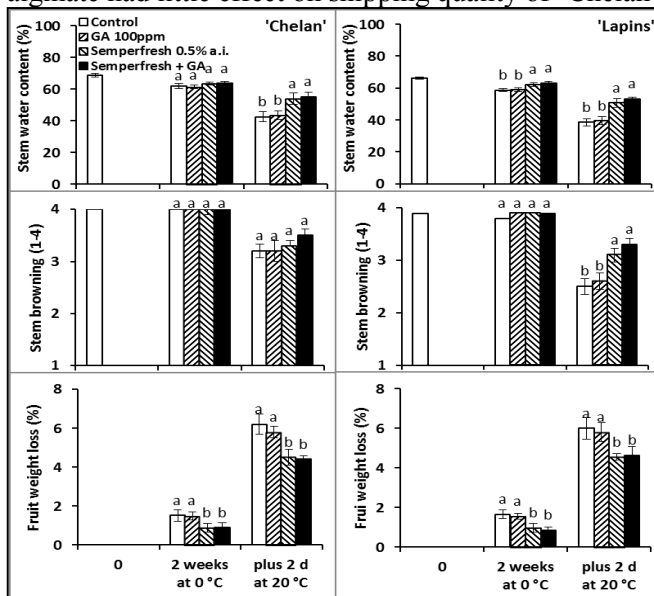


Fig. 14. Effect of Semperfresh™ and GA₃ on shipping quality of Chelan and Lapins at simulated marketing conditions.

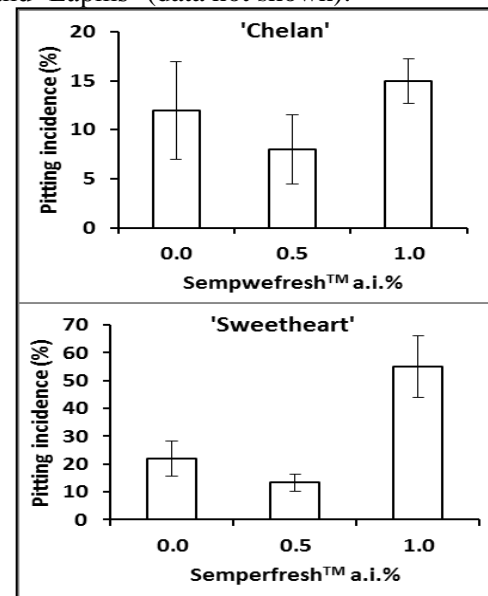


Fig. 15. Effect of Semperfresh™ on pitting incidences of Chelan and Sweetheart after 2 weeks of cold storage.

EXECUTIVE SUMMARY

Project title: Extending storage/shipping life and assuring good arrival of sweet cherry

Due to a high respiratory activity, minimal reserve carbohydrate, and high susceptibility to mechanical damage and water internalization injury, sweet cherries are highly perishable and have a shelf life of only about 2 weeks under cold chain management. Their shelf life is often shortened due to loss of flavor, darkening of fruit skin color, pitting, splitting, pedicel browning, and decay development. Choosing the MAP liners with right gas permeability and postharvest Ca treatment are found to improve shipping quality of sweet cherries.

Modified atmosphere packaging (MAP).

Understanding respiration dynamics influenced by O₂ and CO₂, temperature, and cultivars is an essential knowledge for reducing respiration rate and extending storage/shipping life of cherries. We found that while respiration rate of PNW and California cultivars was inhibited linearly by reduced O₂ concentration from 21% to 3-4% at 20 °C, it was affected very little from 21% to ~10% but declined significantly from ~10% to ~1% at 0 °C. Estimated fermentation induction points were ~1 - ~4% O₂ for PNW and California cultivars depending on temperature. CO₂ between 0-15% did not affect respiration rate, but inhibited fruit skin darkening by retarding anthocyanin accumulation.

The commercially available MAP box liners for sweet cherries were found to have extremely varied gas permeability (i.e., 1-15% O₂ + 5-15% CO₂). While all the MAP liners maintained higher fruit firmness, greener stem, and reduced decay, only the MAP liner with 5-8% O₂ maintained higher TA and better flavor by reducing respiration rate. The MAP liners with 10-15% CO₂ maintained shiner skin color. The MAP liners with 1-2% O₂ increased fruit ethanol accumulation and therefore anaerobic flavor after storage/shipping. Most of the PNW and California cherry cultivars packed in the MAP liners with 5-8% O₂ did not accumulate ethanol at temperature fluctuation between 32-41 °F. Skeena is more susceptible to anaerobic injury and should be packed in MAP liners with 8-10% O₂.

Implementing Ca in hydro-cooling water (5 min)

Calcium (Ca²⁺) plays an extremely important role in the fruit for cell wall structure and strength, plasma membrane structure and integrity, and cellular signaling responses. However, fruit are often deficient in Ca due to its low mobility in plants. Enhancing Ca content can be extremely beneficial in reducing disorders and maintaining quality of fruit during storage. We found that cherry fruit tissue Ca content increased significantly as Ca rate increased from 0.2% to 2.0% at 0 °C for 5 min. The increase of fruit tissue Ca content was accompanied by reductions in respiration rate, ascorbic acid degradation, and membrane lipid peroxidation, which enhanced total phenolics content and total antioxidant capacity, and resulted in increases in fruit firmness and pitting resistance and decreases in titratable acidity loss and decay. The enhanced tissue Ca content also reduced cherry fruit splitting potential by decreasing fruit soluble pectin release and increasing the splitting threshold. In contrast, depleting Ca from fruit tissue by EDTA or low pH increased soluble pectin release and splitting potential. Pedicel browning was inhibited by Ca at 0.2-0.5%, but increased by higher rates at 1.0-2.0%, possibly via modifying membrane lipid peroxidation.

Edible coatings and GRAS compounds

Some benefits on cherry fruit quality from applications of edible coatings and GRAS compounds are reported in literatures. We did not find significant improvement at commercial level on shipping quality of PNW cultivars by postharvest applications of SA, OA, JA, MeJA, ethanol, HBR, GA₃, sodium alginate, chitosan in our conditions. Semperfresh™ helps reducing stem browning, but the rate at 1.0% a.i. may increase pitting expression for certain cultivars.