FINAL PROJECT REPORT

Project Title: Ensuring long-distance ocean shipping arrival quality of PNW cherries

PI: Yu Dong
Organization: OSU MCAREC
Telephone: 541-386-2030 (ext. 38229)
Email: dongyu@oregonstate.edu
Address: 3005 Experiment Station Dr.
City: Hood River/OR/97031

Cooperators: Steve Castagnoli, Jinhe Bai, Johnny Gebbers, Ines Hanrahan, Dan Pariseau

Total Project Funding: **Year 1:** $45,542 **Year 2:** $46,794 **Year 3:** $48,086

Budget History:

Item	Year 1: 2016	Year 2: 2017	Year 3: 2018
WTFRC expenses			
Salaries	29,407[1]	30,289	31,198
Benefits	5043[2]	5245	5455
Wages	4,584[3]	4,722	4,864
Benefits	1,008[4]	1,038	1,069
Equipment			
Supplies	5,000[5]	5,000	5,000
Travel	500[6]	500	500
Plot Fees			
Miscellaneous			
Total	45,542	46,794	48,086

Footnotes:
[1]Postdoctoral Research Associate: 2/3 FTE. 3% increase is factored into Year 2 and 3.
[2]OPE: 2/3 FTE at 17.15%. 4% increase is factored into Year 2 and 3.
[3]Wages: 300hr for a Biological Science Tech. at $15.28/hr. 3% increase is factored into Year 2 and 3.
[4]OPE: 22% of the wage, with a 3% annual increase.
[5]Supplies: fruit, fruit quality and nutrient analyses, fruit volatile compound analyses, GC and GC/MS supplies (helium, nitrogen, hydrogen, standard gases), gas tank rental, chemicals, and MCAREC cold room and land use fees.
[6]Travel to grower fields and packinghouses.

OBJECTIVES

Flavor deterioration is a major marketing issue when PNW sweet cherries are subject to long-distance ocean shipping (3-5 weeks). The goals of this project were: 1) to understand the mechanisms of cherry flavor deterioration; 2) identify pre- and postharvest factors affecting flavor deterioration and internal browning; and 3) develop commercially feasible protocols to maintain postharvest quality of PNW sweet cherry cultivars.

SIGNIFICANT FINDINGS

Mechanisms of flavor deterioration

- Desirable flavor was closely associated with the accumulation of malic acid (titratable acidity, TA), not soluble solids content (SSC).
- Bland flavor mainly resulted from the loss of 2-hexen-1-ol (fruity odor) and accumulation of benzaldehyde (almond-like odor).
- During storage, TAC (total antioxidant capacity), DPPH (2, 2-diphenyl-1-picrylhydrazyl radical-scavenging capacity), FRAP (ferric-reducing antioxidant power), and TP (total phenolic content) decreased significantly, while MDA (malondialdehyde) and O-quinones increased.
- Loss of TAC, DPPH, FRAP, and TP were associated with reduction in TA.
- The decrease of TP was accompanied by the increase of O-quinones. Severe internal browning (IB) and bitter flavors were associated with high O-quinones level.
- MDA was significantly correlated with flavor deterioration, IB, and bitter taste. It may be a good indicator for evaluation of cherry quality.

Identify pre- and postharvest factors affecting flavor deterioration and shipping quality

- Bland flavor was positively correlated with TA reduction, and negatively correlated with SSC/TA ratio. If fruit had < 0.6% TA or > 30 SSC/TA ratio, bland flavor developed.
- Fruit harvested in the morning had greater fruit firmness (FF) and lower risk of fruit flesh extrusion.
- Sustained high temperatures for three days before harvest significantly decreased FF at harvest, but did not affect flavor degradation during fruit storage.
- A pre-harvest simulated rain event did not affect ‘Lapins’ and ‘Skeena’ fruit quality parameters, but a rainfall event in 2016 totaling 0.34 inch resulted in high rates of fruit cracking.
- Fruit calcium (Ca) levels affected flavor deterioration. Fruit with higher calcium concentration were more resistant to softening, loss of TA, and flavor deterioration.
- Fruit harvested at optimum maturity (i.e. Ctifl color score of 6 for ‘Bing’) had extended fruit storage and flavor life.
- Ultraperf modified atmosphere packing (MAP) liners with an equilibrated O_2 7-8% + CO_2 8% maintained flavor and desirable qualities of cherries better than the same liners with an equilibrated O_2 11-13% + CO_2 7% after 5 weeks at 32 °F.
- Rapid forced-air cooling immediately after packing was extremely important to maintaining TA, flavor and other quality attributes during subsequent storage.
- Storage temperatures ≥ 36 °F accelerated quality and flavor loss. ‘Regina’ was more sensitive to high storage temperature than ‘Lapins’.

Determine reliable predictors for cherries with long postharvest flavor life

- For ‘Skeena’, flavor life was significantly positively correlated with TA, TAC, P, K, Ca, and Zn.
- For ‘Lapins’ and ‘Sweetheart’, flavor life was positively correlated with TA and TAC.
- Regardless of orchard location, Ca level was significantly positively correlated with TA in ‘Sweetheart’ and ‘Skeena’. Fruit with high Ca levels had longer flavor life.
- TA and TAC may be good indicators of the potential for long-lasting postharvest flavor.

RESULTS

1. Mechanisms of flavor deterioration of sweet cherries after 5 weeks of cold storage

a. Changes in SSC and TA

During 2016-2018, 'Skeena' was harvested 1 day before commercial harvest date from the experimental orchard at the MCAREC. TA (malic acid) degraded at a relatively fast rate following 5 weeks of storage at 32 °F. However, SSC did not change significantly between harvest and week 5 (Fig. 1A). The positive correlation was significant between flavor and TA (r = 0.845), while no significant correlation was observed between flavor and SSC (r = 0.213) (Fig. 1B). These results indicated that good flavor development was dependent on the levels of TA. Fruit with greater TA retained good flavor for longer periods.

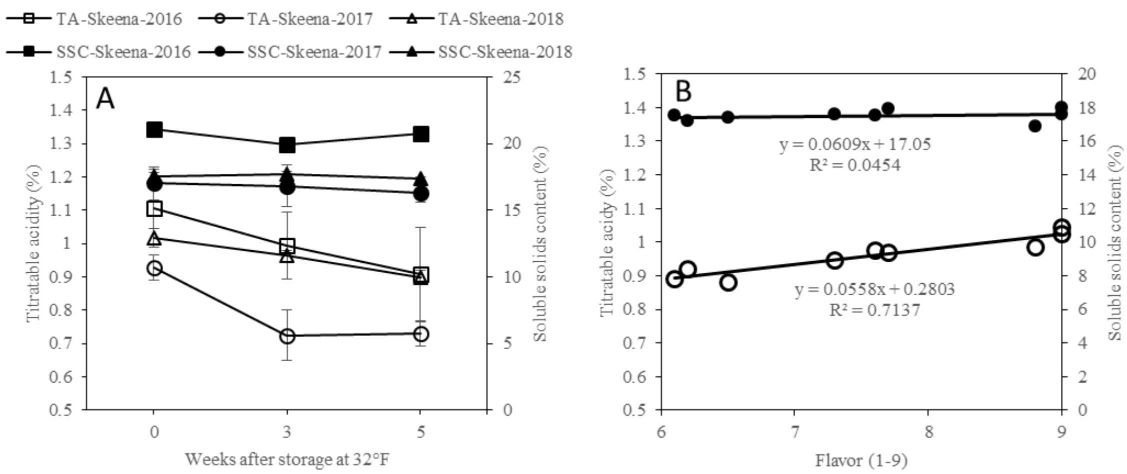

Fig. 1 *(A) Changes in TA (open symbols) and SSC (closed symbols) of 'Skeena' during 5 weeks of storage at 32 °F in 2016-2018; (B) The correlation between flavor and TA (open circles) or SSC (closed circles) in 2018.*

***b. Changes of volatile aroma compounds*: GC-MS (mass spectrometry)**

Volatile aroma compounds of 'Skeena' harvested from five orchards were analyzed at harvest and after 5 weeks of storage. Nineteen volatile aroma compounds were identified by GC-MS (Table 1). These compounds consisted of 7 alcohols (1-penten-3-ol; 3-methyl-3-buten-1-ol; 2-penten-1-ol; 2-methyl-2-buten-1-ol; 2-hexen-1-ol; hexanol; benzyl alcohol), 8 aldehydes (acetaldehyde; pentanol; 2,4-hexadiene; 3-hexenal; hexanal; 2-heptenal; 2-hexenal; benzaldehyde), 1 alkane (dodecane), 1 ester (butyl butyrate), 1 furan (2-ethyl furan), and 1 terpene (limonene). The major compounds are 2-hexanal, hexanal, 2-hexen-1-ol, and hexanol. Compared to levels at harvest, acetaldehyde, pentanol, 2, 4-hexadiene, 2-penten-1-ol, 2-hexen-1-ol, benzyl alcohol, and limonene decreased significantly during storage, while benzaldehyde increased. As a result, the loss in 2-hexen-1-ol (fruity odor) and accumulation of benzaldehyde (almond-like odor) imparted bland flavor.

c. Dynamics of TAC, DPPH, FRAP, MDA, TP, O-quinones

After cherries were packed and placed into cold storage, lipid peroxidation and reactive oxygen species (ROS) gradually increased and induced oxidative damage in fruit. MDA levels were associated with lipid peroxidation and indirect loss of membrane integrity in storage. Levels of TAC, DPPH, and FRAP reflected the capacity of fruit to scavenge ROS. During storage at 32 °F for 5 weeks, TAC, DPPH, and FRAP in 'Skeena' significantly decreased, while MDA increased (Table 2), indicating that the amount of MDA and ROS generated in storage reduced fruit antioxidant capacity, which was followed by rapid deterioration of fruit quality. The mechanism of IB development is unknown but it is generally accepted that oxidation produces TP, identified as O-quinones, which give fruit a brown color and bitter taste. We found that the decrease of TP was associated with an increase of O-quinones. The severe IB and bitter flavor were accompanied by a relatively high level of O-quinones (Table 3).

Table 1. *Aromatic volatile compounds identified in 'Skeena' cherries from 5 orchards at harvest and after 5 weeks storage at 32 °F.*

Compound	Orchard 1-H	Orchard 1-5w	Orchard 2-H	Orchard 2-5w	Orchard 3-H	Orchard 3-5w	Orchard 4-H	Orchard 4-5w	Orchard 5-H	Orchard 5-5w
Alcohols										
1-Penten-3-ol	0.41	0.48	0.85	0.54	0.69	0.67	0.82	0.9	1.05	0.9
3-Methyl-3-Buten-1-ol	1.93	2.49	3.2	2.28	2.2	2.73	2.22	2.99	1.34	1.82
2-Penten-1-ol	0.25	0	0.35	0	0.25	0	0.58	0	0.31	0
2-Methyl-2-buten-1-ol	2.81	2.02	3.52	1.47	1.65	2.13	2.13	1.32	1.27	1.3
Benzyl alcohol	4.33	2.75	5.2	2.97	7.11	4.27	13.88	9.76	2.11	1.43
Hexanol	21.9	18.39	37.99	22.88	18.17	23.64	26.79	23.16	22.53	17.33
2-Hexen-1-ol	71.07	40.35	100.92	48.76	91.95	48.71	83.54	47.43	55.95	37.66
Aldehydes										
Acetaldehyde	0.73	0.65	1.05	0.45	1.06	0.56	1.02	0.69	0.83	0.6
Pentanol	0.43	0.38	0.54	0.26	0.49	0.3	0.47	0.3	0.41	0.22
2,4-Hexadiene	1.33	0.76	2.06	1.03	1.86	0.96	1.81	1.13	1.3	0.86
3-Hexenal	2.74	2.16	2.06	2.41	3.2	4.19	3.15	2.77	3.94	3.22
2-Heptenal	3.75	3.19	2.58	3.73	4.95	6.81	6.16	4.18	6.43	5.07
Benzaldehyde	4.72	7.47	7.25	10.84	8.51	16.21	18.83	29.21	6.22	14.11
Hexanal	44.38	46.97	39.47	40.94	53.52	55.17	66.4	47.45	56.58	57.44
2-Hexenal	132.9	114.29	108.56	127.68	161.76	192.67	171.61	135.52	187.64	151.62
Alkane										
Dodecane	0.81	0	0.53	0	0.54	0	0	0	0	0
Ester										
Butyl butyrate	7.22	6.74	6.93	5.01	4.69	5.98	7.21	5.8	6.91	5.25
Furan										
2-Ethyl furan	0.43	0.47	0.73	0.45	0.88	0.72	1.42	0.85	0.88	0.97
Terpen										
Limonene	20.76	0.78	9.55	5.2	4.76	1.86	5.87	1.27	5.57	1.37

H: at harvest; 5w: after 5 weeks of storage. Data were presented by total ion 10^7.

Table 2. *Changes in TAC, DPPH, FRAP, MDA, TP, and O-quinones of 'Skeena' at harvest and after 3 and 5 weeks of storage at 32 °F.*

	TAC (mM g^{-1})	DPPH (mM g^{-1})	FRAP (mM g^{-1})	MDA (mM g^{-1})	TP (mg g^{-1})	O-quinones (ΔOD)
At harvest	14.77 ± 0.49 a	623.31 ± 58.38 a	1.51 ± 0.12 a	16.73 ± 1.56 c	2.11 ± 0.12 a	0.14 ± 0.02 b
3 Weeks storage	12.91 ± 1.46 b	480.91 ± 27.26 b	0.80 ± 0.08 b	21.54 ± 3.92 b	1.89 ± 0.08 b	0.17 ± 0.01 a
5 Weeks storage	12.84 ± 0.11 b	465. 49 ± 49.46 b	0.65 ± 0.08 c	36.98 ± 8.97 a	1.79 ± 0.09 b	0.18 ± 0.01 a

Data within columns with different letters are significantly different by Fisher's protected least significant difference test (LSD) at $P < 0.05$.

d. Correlation of fruit physiology and biochemistry with fruit flavor evaluations

For 'Skeena', the development of desirable flavor was positively correlated with TA, TAC, DPPH, FRAP, and TP, while negatively correlated with MDA, O-quinones, IB, and bitter taste (Table 3). The development of IB was positively correlated with MDA and bitter taste, while negatively correlated with FRAP, TP, and flavor score. The development of bitter taste was positively correlated with MDA and IB, while negatively correlated with flavor score. TA was significantly correlated with TAC, DPPH, FRAP, and TP in fruit. Additionally, MDA was negatively correlated with flavor score, and positively correlated with IB, and bitter taste. MDA may be a good indicator of cherry quality.

Table 3. *Correlations among fruit physiology, biochemistry, and fruit flavor evaluations in 'Skeena'.*

	FF	Size	TA	SSC	TAC	DPPH	FRAP	MDA	TP	O-quinones	Flavor	IB	Bitter
FF	1	-0.614	-0.133	**-0.851****	0.399	-0.050	0.071	0.185	0.275	0.049	-0.117	0.092	0.186
Size		1	0.606	**0.717***	0.077	0.591	0.303	-0.009	0.049	-0.146	0.267	-0.082	-0.120
TA			1	0.396	**0.717***	**0.956****	**0.903****	-0.506	**0.696***	**-0.727***	**0.820****	-0.569	-0.488
SSC				1	-0.151	0.371	0.083	-0.219	-0.212	-0.097	0.295	-0.226	-0.274
TAC					1	**0.756***	**0.801****	-0.541	**0.729***	-0.645	**0.719***	-0.522	-0.436
DPPH						1	**0.845****	-0.481	0.665	-0.562	**0.782***	-0.602	-0.540
FRAP							1	**-0.679***	**0.921****	**-0.864****	**0.910****	**-0.730***	-0.640
MDA								1	-0.601	0.662	**-0.850****	**0.863****	**0.838****
TP									1	**-0.783***	**0.807****	**-0.736***	-0.658
O-quinones										1	**-0.852****	0.627	0.541
Flavor											1	**-0.903****	**-0.848****
IB												1	**0.983****
Bitter													1

*, ** Indicate significant at 0.05 and 0.01 *P* level.

2. Identify pre- and postharvest factors affecting flavor deterioration

a. Cultivars

During 2016-2018, TA and SSC/TA ratio were measured in five cultivars ('Bing', 'Lapins', 'Regina', 'Skeena', 'Sweetheart') after 5 weeks of storage at 32 °F. The development of bland flavor was positively correlated with the levels of TA (r = 0.935) in fruit, while negatively correlated with SSC/TA ratio (r = 0.810) (Fig. 2). For example, fruit with TA < 0.6% or SSC/TA ratio > 30 cherries developed bland flavor. Thus, TA or SSC/TA ratio may be good indicators of the potential for bland flavor development.

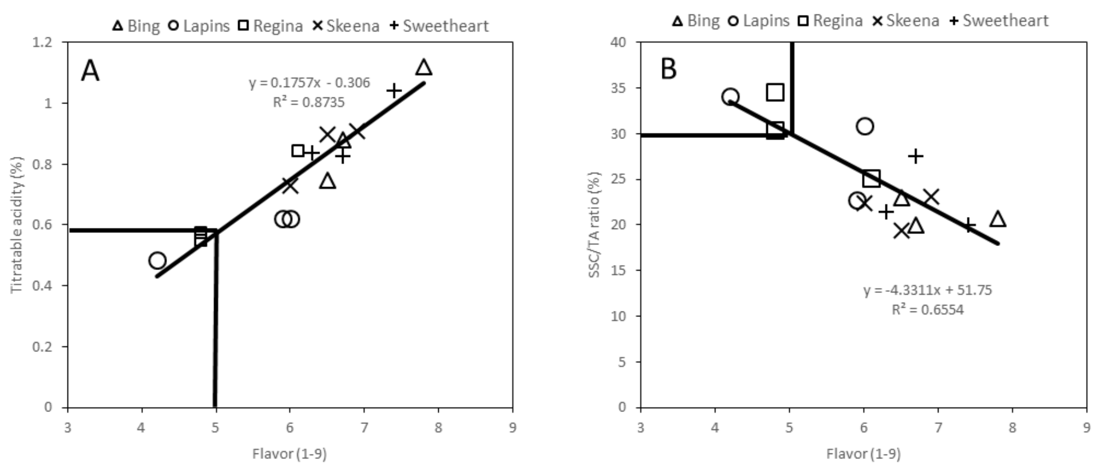

Fig. 2. *(A) Correlation between flavor and TA; (B) SSC/TA ratio of 'Bing', 'Lapins', 'Regina', 'Skeena', and 'Sweetheart' after 5 weeks of storage at 32 °F.*

b. Ambient temperature at harvest

On July 2, 2018 the high temperature was 84 °F; the low was 58 °F. 'Lapins' cherries were harvested at 9 AM when the ambient air temperature was 62 °F, or harvested at 3 PM when the ambient air temperature was 82 °F. Fruit harvested at 9 AM had higher FF than fruit harvested at 3 PM, but no significant differences were observed in SSC or TA (Table 4). After fruit was cooled and stored at 32 °F for 5 weeks, there were no differences in FF, SSC, TA, or flavor. Results indicated that harvesting cherries in the morning is generally preferable to the afternoon, because high FF provided a benefit in resisting fruit flesh extrusion during harvest, though no differences were observed in fruit quality attributes or flavor after storage.

Table 4. *Effect of ambient temperature at harvest on quality attributes and flavor of 'Lapins' at harvest and after 5 weeks of storage at 32 °F.*

Treatments	At Harvest			Week 5			
	FF (g mm^{-1})	SSC (%)	TA (%)	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)
9 AM – 62°F	**298.30 ± 4.76 a**	18.27 ± 0.75 a	0.98 ± 0.11 a	338.07 ± 25.22 a	17.70 ± 0.78 a	0.67 ± 0.05 a	5.83 ± 0.25 a
3 PM – 82°F	**273.03 ± 3.76 b**	18.33 ± 0.45 a	1.05 ± 0.06 a	323.07 ± 10.50 a	17.93 ± 1.24 a	0.66 ± 0.01 a	5.90 ± 0.36 a

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

In 2018, the commercial harvest date for 'Regina' was July 9 at MCAREC. Fruit were collected at ~9 AM on July 2, 5, and 8; daily maximum and minimum temperatures are listed in Table 5. Early harvest resulted in greater FF at harvest and after 5 weeks of storage, slightly higher SSC, while no effects were observed on TA and flavor (Table 6). A 4 day heat spell (July 4 through July 7) resulted in a greater rate of loss of FF for fruit harvested on July 8. Thus, sustained high temperature before harvest decreased fruit FF, but had no effect on flavor during fruit storage in this study.

Table 5. *Harvest date (red) and daily temperature (°F) before 'Regina' harvest in 2018.*

	July 2	July 3	July 4	**July 5**	July 6	July 7	**July 8**
High temperature	**74**	84	91	**94**	91	87	**95**
Low temperature	**58**	55	54	**57**	67	61	**54**

Table 6. *Effect of harvest date on quality attributes and flavor of 'Regina' at harvest and after 5 weeks of storage at 32 °F.*

Date	At Harvest			Week 5			
	FF (g mm^{-1})	SSC (%)	TA (%)	**FF (g mm^{-1})**	SSC (%)	TA (%)	Flavor (1-9)
July 2	**278.13 ± 7.58 a**	21.40 ± 0.46 a	0.92 ± 0.02 a	**336.17 ± 4.31 a**	22.07 ± 0.21 a	0.85 ± 0.05 a	6.10 ± 0.10 a
July 5	**268.67 ± 2.52 b**	21.33 ± 0.42 a	0.95 ± 0.04 a	**324.67 ± 5.51 b**	21.47 ± 0.55 b	0.83 ± 0.03 a	5.97 ± 0.15 a
July 8	**249.17 ± 4.19 c**	20.67 ± 0.40 b	0.97 ± 0.06 a	**302.80 ± 10.9 c**	21.20 ± 0.26 b	0.84 ± 0.02 a	5.80 ± 0.20 a

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

c. Simulated rain

In 2017, 8 gallons of tap water were sprayed with a hand-pressure sprayer over the course of 25 minutes on 'Lapins' and 'Skeena' trees, 1 day before commercial harvest. The ambient air temperature was ~87 °F and the water temperature ~69 °F. Fruit were harvested before this simulated rain, and then again after 8 h. No significant differences were observed in FF, SSC, TA, or flavor between fruit treated or not treated with simulated rain (Table 7). In 2016, a rainfall event totaling 0.34 inch occurred 9 d before the commercial harvest. Fruit cracking was 20% and 49% for 'Lapins' and 'Skeena', respectively.

Table 7. *Effect of simulated rain on quality attributes and flavor of 'Lapins' and 'Skeena' at harvest and after 5 weeks of storage at 32 °F.*

Cultivar	Treatment	At harvest			Week 5			
		FF (g mm^{-1})	SSC (%)	TA (%)	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)
Lapins	Before rain	331 ± 9	16.1 ± 1.1	0.53 ± 0.02	363 ± 32 a	16.0 ± 1.3 a	0.46 ± 0.03 a	6.1 ± 0.2 a
Lapins	After rain	-	-	-	360 ± 15 a	16.3 ± 1.2 a	0.45 ± 0.06 a	6.1 ± 0.2 a
Skeena	Before rain	354 ± 7	17.0 ± 1.2	0.55 ± 0.03	359 ± 22 a	16.3 ± 0.7 a	0.49 ± 0.02 a	6.8 ± 0.3 a
Skeena	After rain	-	-	-	353 ± 31 a	16.3 ± 0.8 a	0.48 ± 0.02 a	7.1 ± 0.2 a

Data within columns and each cultivar with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

d. Fruit calcium content

In earlier studies, we determined a Ca spray rate of 0.1-0.15%, application timing starting at pit-hardening, and frequency of 6 applications at weekly intervals from pit-hardening to harvest were optimal for increasing fruit tissue Ca content. In 2017, $Ca(NO_3)_2$ was applied at the rate of 0.42% (Ca rate at 0.15%, 3.5 lb/acre, 100 gal/acre) 6 times at weekly intervals from pit-hardening to harvest. These pre-harvest Ca applications significantly increased tissue Ca content and FF of 'Skeena', 'Lapins', and 'Regina' cherries at harvest (Table 8). After 5 weeks of storage, Ca-treated fruit maintained higher FF, TA, and flavor. Thus, pre-harvest Ca sprays may improve fruit quality and extend flavor life.

Table 8. *Effect of preharvest $Ca(NO_3)_2$ sprays on tissue Ca content, quality attributes, and flavor of 'Skeena', 'Lapins', and 'Regina' at harvest and after 5 weeks of storage at 32 °F.*

Cultivar	Treatments	At Harvest				Week 5			
		Calcium content (mg kg^{-1} DW)	**FF (g mm^{-1})**	SSC (%)	TA (%)	**FF (g mm^{-1})**	SSC (%)	**TA (%)**	**Flavor (1-9)**
Skeena	Control	**400 ± 100 b**	**418 ± 21 b**	21.10 ± 0.85 a	1.10 ± 0.11 a	**485 ± 20 b**	20.77 ± 1.21 a	**0.78 ± 0.02 b**	**7.0 ± 0.2 b**
	$Ca(NO_3)_2$	**517 ± 73 a**	**477 ± 21 a**	20.63 ± 2.97 a	1.15 ± 0.03 a	**533 ± 18 a**	20.13 ± 1.54 a	**0.99 ± 0.03 a**	**7.6 ± 0.3 a**
Lapins	Control	**433 ± 58 b**	**376 ± 2 a**	14.67 ± 0.15 b	0.73 ± 0.01 b	**355 ± 32 b**	16.63 ± 0.15 a	**0.60 ± 0.03 b**	**6.5 ± 0.3 b**
	$Ca(NO_3)_2$	**750 ± 93 a**	**374 ± 19 a**	15.20 ± 0.44 a	0.82 ± 0.05 a	**471 ± 24 a**	15.13 ± 0.40 b	**0.68 ± 0.04 a**	**7.5 ± 0.3 a**
Regina	Control	**533 ± 58 b**	**361 ± 8 b**	17.00 ± 0.44 a	0.68 ± 0.05 a	**410 ± 23 b**	17.43 ± 0.42 a	**0.57 ± 0.01 b**	**6.2 ± 0.2 b**
	$Ca(NO_3)_2$	**922 ± 54 a**	**427 ± 12 a**	17.30 ± 0.61 a	0.71 ± 0.00 a	**458 ± 15 a**	17.03 ± 0.25 a	**0.63 ± 0.04 a**	**7.2 ± 0.2 a**

Data within columns and each cultivar with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

e. Harvest maturity

'Bing' fruit were harvested when average skin color had a Ctifl color score of 4, 5, or 6. Fruit with Ctifl color score of 6 had higher FF, SSC, and TA than early harvested fruit (Table 9). Furthermore, these fruit maintained higher FF, SSC, TA, as well as good flavor after 5 weeks of storage at 32 °F. Harvest at Ctifl color score of 7 or higher resulted in lower TA, and fruit were more susceptible to flavor deterioration, softening, pitting, pedicel browning, and fruit skin luster loss (data not shown). Thus, for 'Bing', harvesting fruit at optimum maturity, i.e. Ctifl color score of 6, can prolong fruit storage and flavor life.

Table 9. *Effect of harvest maturity on quality attributes and flavor of 'Bing' at harvest and after 5 weeks of storage at 32 °F.*

Ctifl color	At Harvest			Week 5			
	FF (g mm^{-1})	SSC (%)	TA (%)	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)
4	257 ± 4 b	17.87 ± 0.15 b	0.57 ± 0.09 c	264 ± 14 b	17.43 ± 0.51 b	0.44 ± 0.01 c	5.5 ± 0.2 c
5	272 ± 29 ab	17.90 ± 0.30 ab	0.75 ± 0.02 b	276 ± 33 ab	17.77 ± 0.32 b	0.70 ± 0.04 b	6.2 ± 0.4 b
6	**284 ± 15 a**	**20.23 ± 0.47 a**	**0.86 ± 0.02 a**	**295 ± 36 a**	**19.33 ± 0.31 a**	**0.82 ± 0.04 a**	**6.9 ± 0.3 a**

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

f. Commercial MAP liners:

O_2 and CO_2 concentrations for Ultraperf MAP liners with low, moderate, and higher gas permeability tested for storage quality and flavor of 'Regina' are shown in figure 3. Compared to the control, a MAP liner with an equilibrated O_2 level of 7-8% + CO_2 level of 8% retained higher TA and better flavor during 5 weeks at 32 °F (Table 10). In contrast, the MAP liner with an equilibrated O_2 level of 11-13% + CO_2 level of 7% had little effect on cherry flavor.

Table 10. *Effect of Ultraperf modified atmosphere packaging (MAP) liners on quality attributes and flavor of 'Regina' after 5 weeks of storage at 32 °F.*

MAP liner	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)
Control	368 ± 15 b	18.6 ± 0.30 a	0.23 ± 0.02 c	6.2 ± 0.5 c
Ultraperf 1	**397 ± 13 a**	**18.9 ± 0.53 a**	**0.35 ± 0.02 a**	**8.5 ± 0.5 a**
Ultraperf 3	373 ± 17 b	18.5 ± 0.49 a	0.25 ± 0.01 b	7.1 ± 0.5 b
Ultraperf 4	389 ± 12 ab	18.9 ± 0.49 a	0.27 ± 0.03 b	7.0 ± 0.2 b

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

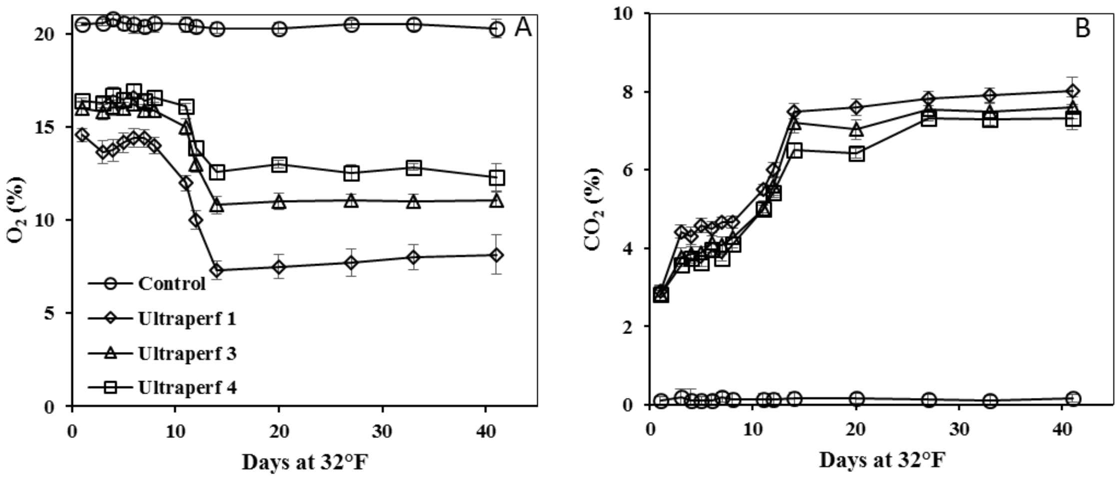

Fig. 3 *O_2 and CO_2 concentrations in Ultraperf modified atmosphere packaging (MAP) liners with 'Regina' cherries at 32 °F.*

g. Post-packing forced-air cooling

In an earlier survey, we determined that fruit pulp temperature at the time of box-filling in some packing houses ranged from 38-45 °F. Under these conditions, pulp temperature was not efficiently reduced to 32 °F in the containers due to the barrier created by the MAP liner reducing heat exchange and retention of heat produced by fruit respiration. In this study, compared to 32 °F, fruit stored at 38 °F or 45 °F had lower FF, and TA as well as greater stem browning and decay after 5 weeks in storage (Table 11). Therefore, rapid forced-air cooling immediately after packing is crucial for flavor (TA) maintenance and other fruit quality characteristics.

Table 11. *Effect of post-packing forced-air cooling on FF, SSC, TA, and flavor of 'Lapins' after 5 weeks of storage at 32 °F.*

Temperature	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)	Stem browning (1-5)	Decay (%)
32°F	415 ± 9 a	17.8 ± 0.22 a	0.74 ± 0.01 a	6.1 ± 0.4 a	4.5 ± 0.2 a	1.8 ± 0.2 a
38°F	374 ± 18 b	17.9 ± 0.36 a	0.69 ± 0.02 b	5.5 ± 0.2 b	4.1 ± 0.1 b	5.8 ± 1.1 b
45°F	353 ± 17 c	17.6 ± 0.29 a	0.55 ± 0.03 c	5.1 ± 0.1 c	2.9 ± 0.2 c	15.1 ± 3.2 c

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

h.Storage temperature

'Lapins' and 'Regina' were harvested 1 day before the commercial harvest date at MCAREC, then fruit were stored at 32 °F, 34 °F, or 36 °F for 5 weeks. After storage, no significant differences were observed in FF, SSC, TA, or flavor score in 'Lapins' cherries stored at 32-36 °F. However, 'Regina' that had been stored at 36 °F had lower FF, SSC, TA, and flavor score than fruit stored at 32 °F or 34 °F (Table 12). Thus, quality and flavor deterioration of 'Regina' was more sensitive to storage and shipping temperature.

Table 12. *Effect of storage temperature on FF, SSC, TA, and flavor of 'Lapins' and 'Regina' after 5 weeks of storage at 32 °F, 34 °F and 36°F.*

Cultivar	Treatments	FF (g mm^{-1})	SSC (%)	TA (%)	Flavor (1-9)
Lapins	32°F	311 ± 5 a	17.70 ± 0.78 a	0.66 ± 0.01 a	5.3 ± 0.3 a
	34°F	315 ± 9 a	17.99 ± 0.53 a	0.65 ± 0.05 a	5.4 ± 0.4 a
	36°F	309 ± 5 a	18.03 ± 0.35 a	0.66 ± 0.03 a	5.3 ± 0.2 a
Regina	32°F	303 ± 11 a	21.20 ± 0.26 a	0.85 ± 0.05 a	6.0 ± 0.2 a
	34°F	301 ± 9 a	21.45 ± 0.47 a0	0.82 ± 0.03 b	5.5 ± 0.3 b
	36°F	**278 ± 4 b**	**20.27 ± 0.25 b**	**0.76 ± 0.02 c**	**5.1 ± 0.1 c**

Data within columns with different letters are significantly different by Fisher's protected LSD test at $P < 0.05$.

3. Determine reliable predictors for cherries with long postharvest flavor life

In 2016, 'Skeena' from 5 Washington orchards were sampled for quality evaluation, flavor, and fruit nutrient content. Fruit were packed in MAP liners and stored at 32 °F. Results indicated that flavor intensity after 5 weeks at 32 °F was significantly positively correlated with TA, TAC, P, K, Ca, and Zn, and negatively correlated with SSC (Table 13).

Table 13. *The correlation among fruit quality attributes, flavor, production elevation, TAC, and fruit nutrients (N, P, K, Ca, Mg, B, Fe, Zn) of 'Skeena' after 5 weeks of storage at 32 °F from 5 orchards in 2016.*

	FF	Size	TA	SSC	Flavor	Elevation	TAC	N	P	Mg	K	Ca	B	Fe	Zn
FF	1	-0.219	-0.295	0.072	-0.165	-0.359	-0.239	0.169	-0.0173	-0.386	0.036	0.086	-0.094	-0.238	0.046
Size		1	-0.210	0.286	-0.411	-0.270	-0.359	-0.435	**-0.584***	-0.421	**-0.565***	**-0.682****	-0.213	**0.656****	-0.387
TA			1	**-0.585***	**0.951****	-0.250	**0.940****	0.140	0.438	0.433	0.477	**0.558***	0.171	0.019	**0.561***
SSC				1	**-0.606***	**0.535***	**-0.684****	**-0.574***	-0.451	-0.081	-0.333	-0.334	**-0.587***	0.118	**-0.646****
Flavor					1	-0.208	**0.970****	0.177	**0.523***	0.430	**0.568***	**0.660****	0.152	-0.131	**0.538***
Elevation						1	-0.272	-0.231	0.069	0.489	0.068	0.094	-0.167	-0.310	-0.371
TAC							1	0.260	**0.530***	0.394	**0.562***	**0.616***	0.229	-0.110	**0.585***
N								1	0.483	0.086	0.264	0.261	0.486	-0.255	**0.534***
P									1	**0.700****	**0.946****	**0.894****	0.477	-0.446	**0.792****
Mg										1	**0.682****	**0.714****	0.467	-0.249	0.480
K											1	**0.937****	0.321	-0.433	**0.762****
Ca												1	0.339	-0.442	**0.723****
B													1	0.035	**0.570***
Fe														1	-0.279
Zn															1

*, ** Indicate significant at 0.05 and 0.01 *P* level.

In 2017, 'Lapins' from 7 Washington orchards and 2 Oregon orchards were sampled for quality evaluation, flavor, and fruit nutrient content. Fruit were packed in MAP liners and stored at 32 °F. Results indicated that flavor intensity after 5 weeks at 32 °F was significantly positively correlated with TA and TAC (Table 14).

Similar 2018 results for 'Sweetheart' from 4 orchards in Washington and 1 in Oregon are shown in Table 15. None of the macronutrients or micronutrients measured were found to be associated with fruit flavor life in 'Sweetheart'. However, in 'Sweetheart' and 'Skeena', Ca was significantly positively correlated with TA. Thus, fruit with high Ca content generally had longer flavor life. TA or TCA can be a good indicator of a cultivar's potential for long postharvest flavor life.

Table 14. *Correlation among fruit quality parameters, flavor, production elevation, TAC, and fruit nutrients (N, P, K, Ca, Mg, B, Fe, Zn) of 'Lapins' after 5 weeks of storage at 32 °F from 9 orchards in 2017.*

	FF	Size	TA	SSC	Flavor	Elevation	TAC	N	P	Mg	K	Ca	B	Fe	Zn
FF	1	**0.625****	0.295	**0.567****	0.006	**0.603****	0.371	0.061	0.051	-0.091	-0.162	-0.191	**0.407***	0.096	0.295
Size		1	**0.406***	**0.691****	0.144	0.247	**0.642****	-0.347	0.316	-0.320	0.024	-0.183	**0.530****	-0.043	**0.390***
TA			1	**0.395***	**0.855****	0.012	**0.793****	-0.070	0.004	-0.269	0.034	-0.102	0.205	0.289	-0.094
SSC				1	0.213	0.211	**0.462***	-0.035	-0.006	-0.167	-0.004	-0.128	0.323	0.266	-0.044
Flavor					1	-0.099	**0.706****	-0.038	0.064	-0.094	0.160	0.052	0.129	0.202	-0.134
Elevation						1	0.033	**0.455***	-0.031	0.233	0.308	**-0.546****	0.297	0.102	0.257
TAC							1	-0.230	0.222	-0.321	0.014	-0.169	0.373	0.235	0.202
N								1	-0.022	**0.622****	0.379	-0.167	-0.032	0.354	-0.192
P									1	0.368	**0.480***	0.185	**0.698****	-0.195	**0.477***
Mg										1	**0.691****	0.262	0.257	-0.132	0.183
K											1	-0.113	**0.458***	0.053	0.213
Ca												1	-0.197	-0.272	0.223
B													1	-0.240	0.359
Fe														1	-0.357
Zn															1

*, ** Indicate significant at 0.05 and 0.01 *P* level, respectively.

Table 15. *Correlation among fruit quality parameters, flavor, production elevation, TAC, and fruit nutrients (N, P, K, Ca, Mg, B, Fe, Zn) of 'Sweetheart' after 5 weeks of storage at 32 °F from 5 orchards in 2018.*

	FF	Size	TA	SSC	Flavor	Elevation	TAC	N	P	Mg	K	Ca	B	Fe	Zn
FF	1	**0.825****	-0.317	**-0.701****	0.145	0.154	-0.419	0.218	**0.729****	-0.095	**0.773****	0.487	**-0.610***	0.165	-0.351
Size		1	0.095	-0.328	0.432	**0.517***	0.034	0.407	**0.720****	0.018	**0.696****	0.247	-0.194	0.370	-0.439
TA			1	**0.817****	**0.730****	**0.584***	**0.969****	0.065	-0.130	0.409	-0.106	**0.769****	**0.808****	0.189	-0.080
SSC				1	0.327	0.488	**0.887****	-0.189	**-0.602***	0.166	**-0.636***	**-0.846****	**0.771****	-0.067	0.094
Flavor					1	0.390	**0.612***	0.016	0.295	0.197	0.379	-0.248	0.413	0.294	0.128
Elevation						1	**0.635***	0.110	-0.075	-0.053	-0.084	**-0.524***	0.314	0.045	-0.247
TAC							1	0.026	-0.268	0.343	-0.268	**-0.823****	**0.849****	0.073	-0.081
N								1	**0.581***	0.213	0.475	0.099	0.181	**0.635***	**-0.581***
P									1	0.171	**0.954****	**0.535***	-0.250	0.436	-0.325
Mg										1	0.189	-0.254	0.403	0.265	-0.332
K											1	0.490	-0.254	0.377	-0.248
Ca												1	**-0.698****	0.250	0.225
B													1	0.155	-0.090
Fe														1	-0.188
Zn															1

*, ** Indicate significant at 0.05 and 0.01 *P* level, respectively.

Executive Summary

In the PNW, more than 1/3 of sweet cherries are exported each year. While airfreight requires 2-3 days, transit time to export markets by sea may range from 3-5 weeks after packing. With protracted transport, flavor deterioration can be a significant issue for PNW cherries upon arrival in export markets. Flavor deterioration includes bland flavor, bitter taste, and anaerobic aroma, and is often associated with IB. Other arrival issues include pitting, luster color loss, pedicel browning, splitting, and decay.

Understand the mechanisms of flavor deterioration

Our current research indicated that desirable fruit flavor was found to be positively correlated with TA (malic acid), but not SSC. Level of TA impacted flavor lifespan. By analyzing the volatile aroma compounds of cherries from five orchards during storage, we found that the loss of 2-hexen-1-ol (fruity odor) and accumulation of benzaldehyde (almond-like odor) imparted bland flavor. During storage, sweet cherries rapidly lost antioxidants, including TAC, DPPH, FRAP, and TP. Meanwhile, lipid peroxidation product (MDA) and browning product (O-quinones) increased and induced IB and bitter taste. MDA was negatively correlated with flavor score, and positively correlated with IB, and bitter taste. MDA may be a good indicator of cherry quality.

Identify pre- and postharvest factors affecting flavor deterioration

This study indicated that cultivar, air temperature at harvest, rain, Ca level, harvest maturity, MAP bag permeability, rapid forced-air cooling, and storage temperature affected the flavor of cherries:

- After storage at 32 °F for 5 weeks, cultivars with high TA level, such as ‘Sweetheart’ and ‘Bing’, or fruit with > 0.6% TA or <30 SSC/TA ratio, demonstrated additional duration of desirable flavor.
- Harvest in the morning was better than afternoon due to the higher fruit firmness and lower fruit flesh extrusion risk. Sustained high temperatures before harvest contributed to rapidly decreasing fruit firmness but did not affected flavor life.
- Simulated rain did not affect flavor life, but a natural rainfall event (0.34 inch in 2016) resulted in high rate of fruit cracking.
- Fruit with higher Ca levels were more resistant to softening, loss of TA, and flavor deterioration.
- Fruit harvested at optimum maturity had longer fruit flavor life.
- Ultraperf MAP liners with an equilibrated O_2 levels of 7-8% + CO_2 levels of 8% maintained better flavor and quality than liners with an equilibrated O_2 level of 11-13% + CO_2 level of 7%.
- Rapid forced-air cooling immediately after packing was highly important for maintaining TA and flavor and other fruit quality attributes during storage.
- Storage temperatures at or above 36 °F accelerated flavor deterioration. Some cultivars, such as ‘Regina’, were more sensitive to storage temperatures.

Determine reliable predictors for cherries with long postharvest flavor life

We determined the correlation among quality attributes, antioxidant, and fruit nutrients of three PNW cherry cultivars (‘Skeena’, ‘Lapins’ and ‘Sweetheart’) from 5-9 orchards located in Washington and Oregon. This work indicated that longer flavor life in ‘Skeena’ was associated with higher TA, TAC, P, K, Ca, and Zn. Flavor life in ‘Lapins’ and ‘Sweetheart’ was significantly positively correlated with TA and TAC and Ca played an important role in enhancing TA level. TA or TAC can be a good indicator of a cultivar’s potential for longer postharvest flavor life.