CONTINUING PROJECT REPORT **YEAR**: No-Cost Extension

Project Title: Postharvest system optimization for organic apple storage

Primary PI: Carolina A. Torres
Organization: Washington State University, Department of Horticulture
Telephone: 509-293-8808
Email: ctorres@wsu.edu
Address: Tree Fruit Research & Extension Center
Address 2: 1100 N Western Av.
City/State/Zip: Wenatchee/WA/98801

Co-PI 2: James Mattheis
Organization: USDA-ARS TFL
Telephone: 509-664-2280 ext. 249
Email: james.mattheis@usda.gov
Address: 1100 N Western Av
Address 2:
City/State/Zip: Wenatchee/WA/98801

Cooperators: David Granatstein (granats@wsu.edu), Lee Kalcsits (lee.kalcsits@wsu.edu), Stemilt Growers, Zirkle Fruit

Project Duration: 3 Years

Total Project Request for Year 1 Funding: $ 50,000.00
Total Project Request for Year 2 Funding: $ 50,600.00
Total Project Request for Year 3 Funding: $ 56,000.00

Other related/associated funding sources:
Valent Biosciences (Retain OL), RipeLocker (vacuum units), WSU, USDA-ARS (CA chambers), Stemilt Growers & Zirkle Fruit (fruit for experiments)
Cost-sharing: $150,000
Notes: Funds for technical support ($30,000/yr), travel expenses ($3,000/yr), and 0.1 FTE (P.I) from start-up funds.

WTFRC Collaborative Costs: None

Budget 1
Primary PI: Carolina Torres
Organization Name: Washington State University
Contract Administrator: Anastasia Mondy
Telephone: 916-897-1960
Contract administrator email address: Anastasia.mondy@wsu.edu
Station Manager/Supervisor: Chad Kruger
Station manager/supervisor email address: ckruger@wsu.edu

Item	2019	2020	2021
Salaries			
Benefits			
Wages	20,000	16,000	16,000
Benefits	7,000	5,600	5,600
Equipment [1]	13,000	13,000	13,000
Supplies[2]	3,500	3,000	3,000
Travel			
RCA rental	6,500	13,000	13,000
Plot Fees			
Total	50,000	50,600	50,600

[1]Three LabPods (Storage Control Systems Inc) leasing for DCA-RQ.
[2]Fruit, laboratory consumables, boxes

OBJECTIVES:

1. Evaluate the combination of DCA systems and RA storage on fruit quality postharvest.
2. Evaluate the effect of organic Retain OL in combination with different storage systems on fruit maturity and quality postharvest.
3. Evaluate the performance of vacuum storage (RipeLocker) under different temperatures regimes on fruit quality and physiological disorder development.

SIGNIFICANT FINDINGS

1. All CA/DCA storage regimes evaluated, including conditioning at harvest and a period in RA in the cold chain after CA/DCA storage, were suitable for long-term storage of Honeycrisp and Fuji apples. Nevertheless, preharvest managements (nutrition, pathogens, etc) and seasonal climate will greatly affect the amount of decay and incidence of physiological disorders during the storage period.
2. In Year 2, soft scald incidence was significantly reduced by all CA/DCA storage regimes compared to Honeycrisp apples stored in air for 4 months. This need to be further study (Year 3 postharvest evaluations are ongoing), because the 2020/2021 season had a low soft scald pressure compared to the previous one.
3. Overall, the application of aminoethoxyvinylglycine (AVG- Retain OL) on Gala (Year 1 and 2) and Honeycrisp (only Year 1) apples effectively delayed fruit maturity progression preharvest, and maintained fruit firmness higher, although not always statistically significant and dose and timing-dependent, until 9 months in CA plus 7 days at 68°F when compared to the untreated control. Skin color development was negatively affected by AVG treatments preharvest in Honeycrisp.
4. Honeycrisp apples stored in low pressure (RipeLocker, RL) at 33°F were comparable in terms of fruit maturity to those stored in CA at 37°F (plus 4 weeks in air). Soft scald incidence was block-dependent the first year and slightly higher in RL-stored fruit in Year 2 (2.5% vs 0.4%). Bitter pit (+lenticel blotch pit) was reduced by vacuum RL in most sites in both years. Similar results in fruit maturity for Fuji apples, as well as overall low disorder incidence in all CA/RL storage protocols.

Objective 1. Evaluate the combination of DCA systems and RA storage on fruit quality postharvest.

Activities:
During Years 1, 2 and 3 temperature and relative humidity sensors were placed in every orchard in spring, and data collected at harvest. Maturity progression was monitored in fruit from all sites for both Fuji and Honeycrisp. This was done by sampling homogeneous fruit from 20 trees per Block 3-4 times (every 7-8 days) before harvest (WBH). At commercial harvest, fruit quality was performed in 18 fruit per Block, and peel samples were collected for further mineral analysis. After conditioning Honeycrisp apples at 50°F for 7 days and Fuji apples by delaying CA imposition for 20 days at 34°F, fruit were placed in different dynamic storage regimes (Table 1). Postharvest evaluations for Year 3 are currently being carried out and will end in July 2022.

RESULTS

Fruit Maturity & Physiological disorders

Honeycrisp: In Year 1, differences in fruit maturity between Blocks after storage (Table 3) followed the same trend observed at harvest (Table 2). In general, fruit in all DCA systems lost 1.5 lb firmness

in average with slight differences between Blocks and storage regimes, after 6 and 9 months plus 4 weeks in RA. In year 2, maturity indices were found mostly different between Blocks or their interaction with storage regimes in the case of I_{AD} (data not shown) and firmness in some time points postharvest (Table 3). In general, TA decreased 0.09% in average after long term storage with differences mostly between fruit from different Blocks and only between storage regimes after 9m+4wk+7 days at RT (Table 3). Overall, TA in Year 1 was higher than in Year 2 throughout storage (Table 3). Although harvest dates were similar or earlier in Year 2 compared to Year 1, fruit was smaller and less firm throughout storage (Table 2 & 3).
In general, decay incidence was below 10% in average after 6 months and 19% after 9 months, with differences between blocks and storage treatments (Table 4). Soft scald appeared after 6 m+4wk+7 days at RT both years, with higher incidences in Year 1, where it also showed a significant interaction Block x Storage regime. This effect was observed until the end of the storage period (Table 4). There was notorious less soft scald in Year 2 in all storage regimes, which was 5 to 10-times less in fruit from blocks W25 and C21 than that of those stored in air for 4 months (6.6% in average for both blocks). Soggy breakdown followed the same trend as soft scald, with significantly higher incidences in Block C21 compared to the rest after 9m+4wk+1 and 7days RT (Table 4). Bitter pit varied between blocks and storage regimes with the highest incidence observed in fruit from W25 and W42 (Table 4).

Fuji: In Year 1, fruit from different blocks were in similar maturity condition at harvest, although some maturity indices showed statistical differences between them (Table 5). In Year 2, slight differences in I_{AD} and SSC between Blocks were observed at harvest (Table 5). Similar trends were observed postharvest, with no major differences between storage regimes (Table 6). Overall, TA in Year 1 was higher than in Year 2 until 9m+4wk+1 d at RT (Table 6).
Decay incidence was below 5% in average after 6 months and 13% after 9 months, with differences between blocks and storage treatments (Table 7). Superficial scald appeared after 9m+4w+7d (shelf-life) with incidences below 5.0% in average and only in Year 1. At this time point, CO_2 injury both seasons with very low incidences (0.6-1.1%) and significant differences between Block x Storage interaction (data not shown). Internal browning was also only observed at this time point and significantly higher in block W40 both years (Table 7).

Table 1. Orchard information includes location, variety, rootstock, year planted, and harvest dates for all seasons.

Block	Location	Variety	Rootstock	Year planted	Harvest date (Year 1)	(Year 2)	(Year 3)
W25	Rock Island	Honeycrisp	B-9	2012	8/31/19	8/27/20	8/26/21
W42	Othello	Honeycrisp	B118	2009	9/2/2019	9/4/20	9/7/21
C21	Royal City	Firestorm	M9 337	1996	9/10/2019	9/1/20	9/3/21
C802	Quincy	Honeycrisp	M9-Pajam2	2010	9/6/2019	9/9/20	9/7/21
W18	Rock Island	Aztec Fuji	M9 337	2009	10/7/2019	10/6/2020	10/1/21
W40	Othello	Fuji	B118/M9-Pajam2	2010	10/3/2019	10/6/2020	10/6/21
C4	Royal City	Aztec Fuji	M26	2006	10/9/2019	10/8/2020	10/6/21
C902	Quincy	Fuji	M9 337	2009	10/4/2019	10/8/2020	10/6/21

Table 2. Maturity indexes (weight, green background color, red coverage, I_{AD}, flesh firmness, soluble solid content, starch index, internal ethylene concentration, IEC, titratable acidity, and respiration) for Honeycrisp apples from different Blocks (W25, W42, C21, C802) at commercial harvest in Year 1 (2019/2020) and Year 2 (2020/2019) seasons.

Year	Orchard	Weight (g)	Background color (1-4)	Red coverage (%)	I_{AD}	Firmness (Lb)	SSC (°Brix)	SI (1-6)	IEC (ppm)	TA (% malic acid)	Respiration Rate (mL CO_2/kg/h)
2019	W25	226.6 b[Z]	2.6 ab[Y]	80.7 a[Y]	0.65 b	16.4 a	15.2 a	4.2	2.8 b	N/A	N/A
	W42	212.9 b	2.1 b	55.7 c	0.82 a	14.1 c	11.8 c	4.4	27.1 a	N/A	N/A

	C21	265.4 a	3.4 a	87.8 a	0.38 c	15.7 ab	13.4 b	5.1	0.0 b	N/A	N/A
	C802	219.4 b	2.2 b	65.8 b	0.81 a	15.0 bc	11.8 c	4.3	10.4 ab	N/A	N/A
	Sign.	**	*	*	**	**	**	NS	**		
2020	W25	169.4 b[Z]	2.9	78.1 b[Y]	0.95 a[Z]	13.2	12.4 ab[Z]	1.8 b[Z]	0.0	0.55 a[Z]	18.6
	W42	176.2 b	2.4	60.3 b	0.87 a	12.6	11.4 b	4.4 a	0.0	0.45 b	18.8
	C21	186.6 b	3.1	94.1 a	0.42 b	13.4	11.5 b	4.7 a	0.0	0.44 ab	5.7
	C802	268.4 a	2.7	63.6 b	0.60 b	13.0	13.5 a	4.4 a	0.1	0.50 ab	14.5
	Sign.	*	NS	*	*	NS	*	*	NS	*	NS

[Z]Means followed by different letters are statistically different (ANOVA, *= P≤0.05; **: P≤0.01; NS: non-significant).Tukey's mean separation test (P≤0.05).
[Y]Kruskall Wallis (P≤0.05) and Dunn's for mean separation.

Table 3. Maturity indexes (flesh firmness, soluble solid content, starch index, titratable acidity internal ethylene concentration) for Honeycrisp apples stored in Controlled atmosphere (**CA**: 3.0% O_2/ 0.5% CO_2; **CA-ILOS**: 0.5% O_2/ 0.5% CO_2- 10 days & 1.0% O_2/0.7% CO_2 thereafter; **CA-RQ**: 3.0% O_2/0.5% CO_2) from different Blocks (W25, W42, C21, C802) at commercial harvest in Year 1 (2019/2020) and Year 2 (2020/2019) seasons.

Factors	Firmness (Lb)		SSC(°Brix)		TA (% malic acid)		IEC (ppm)	
				6m+4w+1d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	14.6 a[Z]	13.8 bc	15.1	13.6 a	0.55 a	0.34 a	86.00	0.00
W42	13.5 b	13.2 c	12.5	11.7 b	0.42 b	0.29 bc	25.90	0.00
C21	13.1 b	14.9 a	12.4	11.6 b	0.42 b	0.27 c	40.33	0.00
C802	14.3 a	13.9 b	12.0	13.6 a	0.53 a	0.34 a	41.50	1.05
Significance	**	*	*	*	**	*	**	NS
Storage (B)								
CA	13.7	13.8	13.0	12.2 b	0.46	0.31	47.29	0.74
CA-ILOS	13.7	14.0	13.0	13.1 a	0.51	0.32	54.79	0.03
CA-RQ	14.1	14.1	13.0	12.5 ab	0.45	0.30	43.22	0.01
Significance	NS	NS	NS	*	NS	NS	NS	NS
A x B	NS	NS	*	NS	NS	NS	**	NS
				6m+4w+7d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	14.6	61.3 a	14.8	13.9	0.47 a	0.28	79.48	0.00
W42	12.5	57.5 b	11.6	11.5	0.32 b	0.24	160.14	2.50
C21	13.2	63.4 a	13.0	12.1	0.45 a	0.24	63.17	0.00
C802	14.4	61.4 a	12.7	13.1	0.47 a	0.29	88.98	2.03
Significance	*	*	*	*	**	NS	NS	NS
Storage (B)								
CA	13.8	61.4	13.0	12.4	0.38 b	0.27	84.46	0.19
CA-ILOS	13.8	59.8	13.1	12.9	0.47 a	0.26	136.80	0.84
CA-RQ	13.5	61.4	12.9	12.6	0.42 ab	0.25	72.58	2.36
Significance	NS	NS	NS	NS	*	NS	NS	NS
A x B	*	NS	*	*	NS	NS	NS	NS
				9m+4w+1d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	68.8 a	62.6	14.8	12.9	0.63 a	0.38 ab	0	0
W42	61.3 b	60.0	11.8	11.2	0.44 c	0.35 ab	0	0
C21	56.3 c	63.6	12.1	11.3	0.47 bc	0.34 b	0	0
C802	66.7 a	59.6	11.8	12.6	0.57 ab	0.39 a	0	0
Significance	**	*	**	*	*	*	NS	NS
Storage (B)								

CA	63.4	61.3	12.6	11.9	0.53	0.38 a	0	0
CA-ILOS	62.8	60.7	12.6	12.3	N/A	0.38 a	0	0
CA-RQ	63.6	62.4	12.7	11.8	N/A	0.34 b	0	0
Significance	NS	NS	NS	*	NS	*	NS	NS
A x B	NS	*	**	*	NS	*	NS	NS
				9m+4w+7d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	65.6 a	59.1 b	15.0	12.6	0.39 b	0.28 b	0.00	0.00
W42	57.2 b	58.0 b	12.2	11.0	0.39 b	0.32 ab	0.07	0.07
C21	53.6 b	63.8 a	12.3	11.5	0.33 b	0.30 ab	0.02	0.02
C802	63.1 a	59.7 b	12.4	12.6	0.50 a	0.35 a	1.01	1.01
Significance	**	*	**	*	**	*	NS	NS
Storage (B)								
CA	58.7	60.8	12.8	11.8	0.400	0.31 b	0.78	0.78
CA-ILOS	60.5	60.2	13.2	12.3	0.397	0.36 a	0.02	0.02
CA-RQ	60.5	59.4	12.9	11.6	0.428	0.26 c	0.02	0.02
Significance	NS	NS	NS	*	NS	*	NS	NS
A x B	NS	NS	**	*	NS	NS	NS	NS

[Z]Means followed by different letters are statistically different (ANOVA, *= P≤0.05; **: P≤0.01; NS: non-significant).Tukey's mean separation test (P≤0.05).

Table 4. Fruit defects (incidence, average %) in Honeycrisp apples stored in Controlled atmosphere with different protocols (**CA**: 3.0% O_2/ 0.5% CO_2; **CA-ILOS**: 0.5% O_2/ 0.5% CO_2- 10 days & 1.0% O_2/0.7% CO_2 thereafter; **CA-RQ**: 3.0% O_2/0.5% CO_2) from different orchard blocks (W25, W42, C21, C802) at 6 months, 6 month or 9 months plus 4 weeks in air plus 1 day or 7 days at room temperature (68°F) in Year 1 (2019/2020) and Year 2 (2020/2019).

					Decay (%)					
	6m		6m+4w+1d		6m+4w+7d		9m+4w+1d		9m+4w+7d	
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.9	1.3	1.3	3.9	7.2	7.8 a	2.2 b	1.1	16.1 a	11.1
W42	1.3	0.9	6.2	3.9	8.3	6.1 ab	5.3 ab	1.1	11.7 ab	4.4
C21	0.4	0.9	5.3	1.1	7.2	1.1 b	12.0 a	0.0	15.0 a	1.1
C802	1.8	0.4	3.1	0.6	8.3	3.3 ab	2.4 b	0.0	6.7 b	2.2
Significance	NS	NS	NS	NS	NS	*	**	NS	*	*
Storage (B)										
CA	1.7 a	0.6	5.3 a	1.7	10.0 a	3.8	4.7 b	0.0 b	12.5 a	4.2
CA-ILOS	1.7 a	0.6	4.3 ab	1.3	9.8 a	3.3	3.3 b	0.0 b	5.8 b	2.5
CA-RQ	0.0 b	1.3	2.3 b	4.2	3.6 b	6.7	9.2 a	1.7 a	18.8 a	7.5
Significance	*	NS	*	NS	**	NS	**	*	*	*
A x B	NS	NS	NS	*	**	NS	*	NS	**	*
					Soft Scald (%)					
	6m		6m+4w+1d		6m+4w+7d		9m+4w+1d		9m+4w+7d	
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.9	0.0	3.1	0.0	4.4	1.7	0.4	0.0	0.6	0.6
W42	8.0	0.0	8.0	0.0	10.6	0.6	5.8	0.0	8.3	0.0
C21	11.1	0.0	12.4	0.0	20.0	0.0	7.1	0.0	12.2	0.0
C802	0.0	0.0	0.4	0.6	0.6	0.6	0.0	0.0	0.0	0.0
Significance	**	NS	**	NS	**	NS	**	NS	**	NS
Storage (B)										
CA	7.3	0.0	9.0	0.4	11.3	1.3	3.7	0.0	5.8	0.4
CA-ILOS	4.3	0.0	5.7	0.0	11.3	0.4	2.3	0.0	4.6	0.0
CA-RQ	3.3	0.0	3.3	0.0	4.2	0.4	3.7	0.0	5.4	0.0
Significance	**	NS	**	NS	**	NS	NS	NS	NS	NS

A x B	**	NS	**	NS	**	NS	**	NS	**	NS
Soggy Breakdown (%)										
	6m		6m+4w+1d		6m+4w+7d		9m+4w+1d		9m+4w+7d	
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.0	0.0	0.0	0.0	0.0	0.6	0.0 b[Z]	0.6	1.1 b	2.2
W42	0.0	0.0	0.0	0.0	1.7	0.0	0.4 b	0.0	1.7 b	0.0
C21	0.0	0.0	0.0	0.0	8.9	0.6	7.1 a	0.0	19.4 a	1.1
C802	0.0	0.0	0.0	0.0	0.0	0.6	0.0 b	0.0	0.0 b	1.7
Significance	NS	NS	NS	NS	**	NS	**	NS	**	NS
Storage (B)										
CA	0.0	0.0	0.0	0.0	6.25	0.0	1.7	0.0	7.5	0.0 b
CA-ILOS	0.0	0.0	0.0	0.0	0.4	0.0	3.3	0.0	6.7	2.5 a
CA-RQ	0.0	0.0	0.0	0.0	1.25	1.3	0.7	0.4	2.5	1.3 ab
Significance	NS	NS	NS	NS	**	NS	NS	NS	NS	*
A x B	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
Bitter Pit (%)										
	6m		6m+4w+1d		6m+4w+7d		9m+4w+1d		9m+4w+7d	
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.0	7.3 a	1.8	10.6 a	4.4	14.4 a	4.4	9.4 a	5.6	9.4 a
W42	8.9	4.7 ab	12.9	9.4 a	19.4	10.0 a	14.3	11.1 a	17.8	13.9 a
C21	7.6	0.4 c	9.8	1.1 b	13.9	1.1 b	10.2	1.7 b	13.9	1.7 b
C802	0.9	0.9 bc	1.3	1.7 b	7.8	2.2 b	5.2	3.3 ab	5.6	3.3 ab
Significance	**	*	**	*	**	*	**	*	**	*
Storage (B)										
CA	3.3	3.5	5.0	5.0	9.2	6.3	6.1	6.7	7.5	7.1
CA-ILOS	5.7	2.6	8.0	5.0	11.7	7.5	12.7	4.6	16.3	5.8
CA-RQ	4.7	3.8	6.3	7.1	13.3	7.1	6.9	7.9	9.6	8.3
Significance	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
A x B	**	NS	**	NS	**	NS	**	NS	**	NS

[Z]Kruskal-Wallis (P≤0.05); [Y]Different letters within columns indicate statistically significant differences (Dunn test).

Table 5. Maturity indexes (weight, green background color, red coverage, I_{AD}, flesh firmness, soluble solid content, starch index, internal ethylene concentration, IEC, titratable acidity, and respiration) for Fuji apples from different Blocks (W18, W40, C4, C902) at commercial harvest in Year 1 (2019/2020) and Year 2 (2020/2019) seasons.

Season	Orchard (A)	Weight (g)	Background color (1-4)	Red coverage (%)	I_{AD}	Firmness (N)	SSC (°Brix)	SI (1-8)	IEC (ppm)	TA (% malic acid)	Respiration Rate (mL CO_2/kg/h)
2019	W18	237.3 b	3.0	93.9	1.13 a	16.6 abc	14.0 a	6.6	0.36	N/A	N/A
	W40	503.1 a	3.0	94.2	0.87 b	17.8 a	13.1 ab	6.1	0.19	N/A	N/A
	C4	244.9 b	3.0	95	1.06 a	17.0 a	13.6 ab	6.2	0.22	N/A	N/A
	C902	523.3 a	3.0	100	1.13 a	16.2 c	11.9 b	6.8	0.32	N/A	N/A
	Sign.	**	NS	NS	**	*	*	NS	NS	-	-
2020	W18	181.0	2.4	91.4	1.04 b	15.4	14.1 a	3.9	0.00	0.35	37.8
	W40	187.2	2.5	81.7	0.67 c	16.4	13.7 a	5.7	0.00	0.38	28.7
	C4	189.1	2.1	79.7	1.07 b	16.3	12.3 b	5.2	0.00	0.35	33.2
	C902	190.0	2.0	74.2	1.26 a	16.9	12.3 b	5.2	0.00	0.33	33.4
	Sign.	NS	NS	*	*	NS	*	NS	NS	NS	NS

[Z]Means followed by different letters are statistically different (ANOVA, *= P≤0.05; **: P≤0.01; NS: non-significant).Tukey's mean separation test (P≤0.05).

Table 6. Maturity indexes (flesh firmness, soluble solid content, starch index, titratable acidity internal ethylene concentration) for Fuji apples stored in Controlled atmosphere (**CA**: 0.8% O_2/ 0.8% CO_2; **CA-ILOS**: 0.6% O_2/ 0.8% CO_2- 10 days & 0.8% O_2/0.8% CO_2 thereafter; **CA-RQ**: 0.8% O_2/0.8% CO_2) from different Blocks (W18, W40, C4, C902) at commercial harvest in Year 1 (2019/2020) and Year 2 (2020/2019) seasons.

Factors	Firmness (N)		SSC(°Brix)		TA (% malic acid)		IEC (ppm)	
				6m+4w+1d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	65.8 a	71.0	14.9 a	15.8	0.372 a	0.299 a	0.0	0.0
W40	67.6 a	74.4	13.5 b	14.7	0.372 a	0.258 ab	0.6	0.1
C4	67.1 a	69.6	14.6 a	13.8	0.291 b	0.197 c	0.1	0.3
C902	62.1 b	75.3	13.4 b	14.4	0.376 a	0.243 bc	0.5	0.0
Significance	**	*	**	*	*	*	NS	NS
Storage (B)								
CA	65.1	72.0	13.9	14.5	0.372 a	0.255	0.0 b	0.0
CA-ILOS	66.6	74.4	14.3	14.9	0.326 b	0.254	0.8 a	0.0
CA-RQ	65.3	71.3	14.1	14.5	0.361 ab	0.238	0.1 b	0.2
Significance	NS	*	NS	NS	*	NS	*	NS
A x B	NS	*	NS	*	NS	NS	NS	NS
				6m+4w+7d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	67.4	72.8 b	15.1 a	15.9 a	0.352 a	0.293 a	0.0	0.0
W40	67.3	76.7 a	14.1 b	14.8 b	0.352 a	0.278 ab	0.0	0.0
C4	66.2	71.3 b	14.6 b	14.1 c	0.278 b	0.191 c	1.8	0.1
C902	65.6	75.5 a	13.4 c	14.3 bc	0.370 a	0.238 bc	1.2	1.4
Significance	NS	*	*	*	*	*	NS	NS
Storage (B)								
CA	65.0 b	73.8 ab	14.0 b	14.8 ab	0.339 ab	0.253	0.0	0.0
CA-ILOS	66.9 a	75.7 a	14.5 a	15.0 a	0.362 a	0.262	0.0	0.1
CA-RQ	67.9 a	72.9 b	14.4 a	14.5 b	0.313 b	0.234	2.3	1.1
Significance	**	*	*	*	*	NS	NS	NS
A x B	NS	NS	NS	NS	NS	NS	NS	NS
				9m+4w+1d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	66.0	73.2	15.2	15.3	0.290	0.289 a[Z]	0.1 b	0.0
W40	66.7	74.7	13.6	14.0	0.303	0.261 ab	1.1 ab	0.0
C4	65.7	70.3	14.3	15.3	0.242	0.187 c	2.2 a	0.0
C902	66.9	75.9	13.0	13.8	0.336	0.252 b	2.2 a	0.0
Significance	NS	*	*	NS	NS	*	*	NS
Storage (B)								
CA	67.3	74.4	14.2	15.4	0.307	0.253	1.4	0.0
CA-ILOS	65.8	74.4	13.9	14.4	0.260	0.251	1.1	0.0
CA-RQ	65.8	71.8	14.0	14.0	0.312	0.237	1.7	0.0
Significance	*	*	NS	NS	NS	NS	NS	NS
A x B	*	*	*	NS	NS	NS	NS	NS
				9m+4w+7d				
Orchard (A)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	69.1	73.5	15.4 a	15.2 a	0.255 a	0.283 a	0.1 b	0.0
W40	67.4	74.7	13.9 bc	14.2 b	0.244 a	0.236 b	0.1 b	0.0
C4	66.1	70.9	14.8 ab	13.9 b	0.170 b	0.199 c	15.2 a	0.2
C902	67.3	75.9	13.4 c	13.8 b	0.265 a	0.231 bc	0.3 b	0.0
Significance	NS	*	*	*	*	*	*	NS
Storage (B)								
CA	68.4	75.3	14.4	14.3	0.250	0.251 a	3.2	0.0
CA-ILOS	67.9	75.3	14.2	14.5	0.222	0.245 a	5.9	0.0
CA-RQ	66.1	70.7	14.5	14.1	0.230	0.215 b	2.6	0.2
Significance	NS	*	NS	NS	NS	*	NS	NS

A x B	NS	*	NS	NS	NS	NS	NS	NS

[Z]Means followed by different letters are statistically different (ANOVA, *= P≤0.05; **: P≤0.01; NS: non-significant).Tukey's mean separation test (P≤0.05).

Table 7. Fruit defects (incidence, average %) in for Fuji apples stored in Controlled atmosphere (**CA**: 0.8% O_2/ 0.8% CO_2; **CA-ILOS**: 0.6% O_2/ 0.8% CO_2- 10 days & 0.8% O_2/0.8% CO_2 thereafter; **CA-RQ**: 0.8% O_2/0.8% CO_2) from different Blocks (W18, W40, C4, C902) at 6 months, 6 month or 9 months plus 4 weeks in air plus 1 day or 7 days at room temperature (68°F) in Year 1 (2019/2020) and Year 2 (2020/2019).

Decay (%)						
	9m		9m+4w+1d		9m+4w+7d	
Orchard (**A**)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	0.4	0.4	0.9	3.9	13.3	5.6 ab
W40	0.9	0.4	4.0	1.7	8.9	10.6 a
C4	0.0	0.4	2.2	2.2	6.7	1.7 b
C902	0.4	0.0	3.6	1.1	10.6	2.8 b
Significance	NS	NS	*	NS	NS	*
Storage (**B**)						
CA	0.7	0.0	2.3	2.1	7.5	5.8
CA-ILOS	0.7	0.3	4.0	2.5	11.3	4.6
CA-RQ	0.0	0.6	1.7	2.1	10.8	5.0
Significance	NS	NS	NS	NS	NS	NS
A x B	**NS**	**NS**	*	**NS**	**NS**	**NS**
Internal Browning (%)						
	9m		9m+4w+1d		9m+4w+7d	
Orchard (**A**)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W18	0.0	0.0	0.0	0.0	0.0 b	0.0 b
W40	0.0	0.0	0.0	0.0	17.2 a	3.9 a
C4	0.0	0.0	0.0	0.0	0.0 b	0.0 b
C902	0.0	0.0	0.0	0.0	0.6 b	0.0 b
Significance	NS	NS	NS	NS	*	*
Storage (**B**)						
CA	0.0	0.0	0.0	0.0	2.9	0.0
CA-ILOS	0.0	0.0	0.0	0.0	3.8	2.1
CA-RQ	0.0	0.0	0.0	0.0	6.7	0.8
Significance	NS	NS	NS	NS	NS	NS
A x B	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

[Z]Kruskal-Wallis (P≤0.05); [Y]Different letters within columns indicate statistically significant differences (Dunn test).

Obj. 2. Evaluate the effect of organic Retain OL in combination with different storage systems on fruit maturity and quality postharvest.

Activities:

During Years 1 and 2 different Retain OL treatments were applied to Gala and Honeycrisp commercial blocks in Hood River, OR (Year 1), and Gala in a. commercial block in Manson, WA. In all experiments treatments consisted in 10 fl oz/acre applied 4 and 1 week before harvest (T2), 20 fl oz/acre. (Full dose), 1 week before harvest (T3) plus an untreated control (T1) in Year 1, and all of them plus full dose 3 (T4) and 1 day (T5) before harvest in Year 2. Fruit was harvested twice: at commercial harvest and 7 days later. Maturity indices were evaluated from 27 days before harvest (DBH) until harvest and after 3, 6, and 9 months in CA storage plus 7 days at room temperature (68°F).

RESULTS

Year 1: When treatments were harvested according to the untreated fruit (H1) optimum maturity, Retain-treated fruit (T2, T3) was only significantly higher after 9 months in CA plus 7 days at RT (9.1 lb versus 7.8 lb) in Gala. Conversely, when they were harvest at the optimum maturity in the Retain-treated fruit (H2, approx. 1 week later), T3 showed consistently (although not always statistically different) higher flesh firmness and SSC from 3 until 9 months of storage than the rest of the treatments, except at 9 months plus 7 days at RT. This was also true in Honeycrisp. Both, T2 and T3 significantly affected red skin color (% coverage) in Honeycrisp apples. There were no consistent differences between treatments in IEC, SI, SSC or I_{AD} in Gala throughout storage. In Honeycrisp apples, only the I_{AD} values were consistently higher (less ripen), but not always statistically different, in Retain OL-treated fruit in comparison to the Untreated control. There were no statistical differences between defects incidences between treatments in any of the experiments.

Year 2: In general, all Retain OL treatments affected flesh firmness, I_{AD}, starch degradation (index) and fruit respiration progression preharvest. Retain OL-treated fruit maintained higher I_{AD}, flesh firmness effectively delaying the commercial harvest. T2 maintained the highest flesh firmness in fruit postharvest, although not always significantly different from T3 in H1 and T3, T4 and T5 in H2. Similar results were observed for the I_{AD} (chlorophyll degradation) values, which were higher (less degraded) in T3 compared to the rest of the Retain treatments (Table 8).

Table 8. Maturity indexes (weight, chlorophyll degradation (I_{AD}), flesh firmness (lb) soluble solid content, starch index, and titratable acidity (% malic acid)) for Gala apples treated with Retain OL (1: Untreated Control; 2: 10 Fl Oz/Ac, 21 DBH+7DBH; 3: 20 Fl Oz/Ac, 7 DBH; 4: 20 Fl Oz/Ac, 3 DBH; 20 Fl Oz/Ac, 1 DBH) and stored in Controlled atmosphere (0.8% O_2/ 0.8% CO_2) for 9 months plus 7 days at 68°F. Year 2 (2020/2019) season.

	Eval. Time	Trt	Wt (g)	I_{AD}	Firmness (lbs)	SSC (°Brix)	Starch Index (1-6)	Acidity (% malic acid)
H2 Gala	3 mo	1	187.91	0.175 a[Z]	13.39 a	13.6 b	6.0 c	0.216
		2	176.31	0.448 b	15.09 b	12.0 a	5.1 a	0.200
		3	187.73	0.465 b	14.48 a,b	12.2 a	5.5 b	0.162
		4	186.67	0.483 b	13.96 a,b	11.9 a	5.9 c	0.207
		5	187.79	0.422 b	14.16 a,b	12.4 a	6.0 c	0.213
	p-value		0.643	<0.001	0.003	<0.001	<0.001	0.173
	3 mo +7d	1	189.84	0.164 a	12.83 a	13.6 b	6.0	0.224 a,b
		2	184.01	0.550 c	14.92 b	12.4 a	6.0	0.232 b
		3	194.74	0.390 b	14.32 b	12.9 a,b	6.0	0.177 a
		4	191.96	0.419 b	14.12 b	12.9 a,b	6.0	0.203 a,b
		5	184.32	0.367 b	14.33 b	12.6 a	6.0	0.218 a,b
	p-value		0.613	<0.001	<0.001	0.001	-	0.033
	6 mo	1	169.77	0.271 a	12.76 a	12.3	8.0	0.105
		2	175.46	0.509 b,c	14.73 c	12.7	8.0	0.110
		3	175.66	0.526 c	14.28 b,c	12.4	8.0	0.138
		4	184.53	0.379 a,b	13.66 a,b	12.7	8.0	0.109
		5	182.68	0.456 b,c	13.89 b,c	12.4	8.0	0.102
	p-value		0.404	<0.001	<0.001	0.444	-	0.626
	6 mo +7d	1	-	0.274 a,b	11.97 a	12.9	8.0	0.094
		2	-	0.531 c	14.88 b	13.1	8.0	0.105
		3	-	0.496 c	14.14 b	12.7	8.0	0.096
		4	195.92	0.321 b	13.97 b	12.7	8.0	0.114
		5	194.56	0.183 a	14.76 b	13.0	8.0	0.121
	p-value		0.865	<0.001	<0.001	0.625	-	0.704

9mo	1	184.84	a	0.172	a	10.50	a	13.4		8.0	0.171
	2	208.89	b,c	0.400	b	14.72	b	13.0		8.0	0.159
	3	197.11	a,b	0.418	b	14.59	b	12.9		8.0	0.168
	4	237.91	c	0.384	b	11.88	a	13.1		8.0	0.140
	5	199.51	a,b	0.370	b	13.73	b	13.0		8.0	0.148
p-value		<0.001		<0.001		<0.001		0.109		-	0.385
9mo +7d	1	198.46	a,b	0.147	a	9.59	a	13.8	b	8.0	0.156
	2	193.13	a	0.360	b	14.87	b	13.3	a,b	8.0	0.197
	3	212.49	b,c	0.327	b	14.00	b	13.2	a,b	8.0	0.190
	4	199.64	a,b	0.300	b	12.63	b	13.2	a,b	8.0	0.193
	5	195.69	a	0.269	a,b	13.35	b	12.8	a	8.0	0.193
p-value		0.020		0.001		<0.001		0.020		-	0.059

[Z]Means followed by different letters are statistically different (ANOVA, P≤0.05).Tukey's mean separation test (P≤0.05).

Objective 3. Evaluate the performance of vacuum storage (RipeLocker) under different temperatures regimes on fruit quality and physiological disorder development.

Activities:
After commercial harvest, fruit from all commercial blocks in Obj. 1 and both cultivars, Honeycrisp and Fuji, were placed in vacuum storage (approx. 10% of regular atmosphere) bins (RipeLockers, RL) at 37°F (only Year 1) and 33°F after conditioning (see Obj. 1). Postharvest evaluations for Year 3 are currently being carried out and will be finish in July 2022.

RESULTS
Honeycrisp: In Year 1, there were no major differences in maturity between vacuum RL and regular CA storage. Nevertheless, fruit stored in RL33 had less chlorophyll degradation (I_{AD} value) and less respiration after 9 months+4 wks+7 days at RT both years. The effect of the storage regime over soft scald was block-dependent in Year 1, and slightly higher in fruit stored in RL33 in Year 2 (Table 9). The same for soggy breakdown in Year 2. Bitter pit (+lenticel blotch pit) was significantly reduced by vacuum RL in most sites, regardless of differences in lot susceptibility. Similar results were observed in Year 2 (Table 9).

Table 9. Physiological disorders (incidence, average %) in Honeycrisp apples from different orchard blocks (W25, W42, C21, C802) stored in Controlled atmosphere (3.0% O_2/ 0.5% CO_2) or vacuum/low pressure in Ripelockers at 37°F (RL37) or 33°F (RL33) for up to 9 months plus 4 weeks in air plus 7 days at 68°F in Year 1 (2019/2020) and Year 2 (2020/2019).

Soft Scald (%)						
	9m		9m+4w+1d		9m+4w+7d	
Orchard (**A**)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.0	0.0	2.6	0.0	0.9 b	1.7
W42	1.6	0.3	3.6	0.8	11.9 a	1.7
C21	5.0	0.3	6.6	0.8	13.5 a	0.8
C802	0.4	0.3	3.1	2.5	6.2 ab	2.5
P value	<0.01	NS	NS	NS	≤0.001	NS
Storage (**B**)						
CA	3.0	0.0	3.7	0.0 b	5.8	0.4 b
LP33	1.4	0.5	4.8	2.1 a	10.2	2.9 a
LP37	0.8	NA	1.5	NA	7.9	NA
P value	NS	NS	NS	≤0.01	NS	≤0.05
A x B	**≤0.01**	**NS**	**≤0.05**	**NS**	**NS**	**NS**
Soggy Breakdown (%)						
	9m		9m+4w+1d		9m+4w+7d	
Orchard (**A**)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2

W25	0.0	0.0	0.0	0.0	0.9	0.0 b
W42	0.0	0.0	0.0	0.0	0.7	2.5 a
C21	0.0	0.0	2.2	0.0	12.8	0.0 b
C802	0.0	0.0	0.0	0.0	0.9	0.0 b
P value			≤0.05		NS	≤0.05
Storage (**B**)						
CA	0.0	0.0	1.7	0.0	7.5	0
LP33	0.0	0.0	0.0	0.0	2.1	1.3
LP37	0.0	NA	0.0	NA	1.0	NA
P value			≤0.05		NS	NS
A x B			**≤0.01**		**NS**	**≤0.05**
			Bitter pit + Lenticel blotch pit (%)			
	9m		9m+4w+1d		9m+4w+7d	
Orchard (**A**)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
W25	0.0	4.8 a	1.8	14.2 a	2.0	14.2 a
W42	6.1	6.1 a	9.4	7.5 a	14.4	9.2 a
C21	2.7	0.6 b	5.7	0.8 b	8.1	0.8 b
C802	3.3	1.3 ab	5.3	1.7 b	9.0	1.7 b
P value	≤0.01	≤0.01	≤0.05	≤0.001	≤0.01	≤0.001
Storage (**B**)						
CA	2.4	5.1	6.4	6.7	7.9	7.5 a
RL33	3.7	1.3	5.3	5.4	7.4	5.4 b
RL37	3.0	NA	5.0	NA	9.4	NA
P value	NS	≤0.01	NS	NS	NS	≤0.05
A x B	≤0.001	**NS**	NS	**NS**	**NS**	**NS**

[Z]Kruskal-Wallis (P≤0.05); [Y]Different letters within columns indicate statistically significant differences (Dunn test).

Fuji: In Year 1, fruit maturity at harvest and during the storage season was mostly similar between treatments (Block x Storage regime), with some exceptions where the maturity index was block-dependent, especially after 9 months of storage (Table 3). Superficial scald appeared after 9m+4w+7d. The effect of the storage regime over its expression was block-dependent. No superficial scald was observed in Year 2. Internal browning, CO2 injury and bitter pit incidences were below 4% in average and mostly in Year 1.