

Project Title: Ultra-low O₂ CA strategies to reduce 'd'Anjou' storage disorders

Report Type: Final Project Report

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Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$ 68,937

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Total Project Request for Year 3 Funding: \$ 71,910

Other related/associated funding sources: Awarded

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Agency Name: USDA-ARS

Notes: In-house project with complimentary objectives. Funds (over 3 years) for ½ storage maintenance and costs (\$12,000), supplies and materials (\$9000), travel (\$3000), and 0.2 FTE (PI and Co-PI) and 0.5 FTE Postdoctoral research associate (\$113,742).

WTFRC Collaborative Costs: None.

Budget 1

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Item	2022	2023	2024
Salaries*	27000	28080	29203
Benefits	9437	9815	10207
Wages	5000	5000	5000
Benefits			
Equipment			
Supplies	5000	5000	5000
Travel			
Miscellaneous**	12500	12500	12500
Plot Fees			
Total	58937	60395	61910

Footnotes: *0.5 FTE WSU postdoc at WSU benefits rate. **1/5 of instrument service contract to be used for project activities.

Budget 2

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Item	2022	2023	2024
Salaries			
Benefits			
Wages	10000	10000	10000
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous			
Plot Fees			
Total	10000	10000	10000

Footnotes: Part-time wages to perform fruit quality analysis

OBJECTIVES:

1. Identify temperature and atmospheric storage combinations that reduce superficial scald without causing or exacerbating other disorders.
2. Determine what post-storage ripening and scald controls can be used following ultra-low oxygen (ULO) controlled atmosphere (CA).
3. Evaluate tests that indicate disorder control effectiveness during ULO CA.

SIGNIFICANT FINDINGS:

1. ULO storage (0.5% O₂) reduces or controls superficial scald of d'Anjou pears.
2. Black speckling developed on some orchards in one season in ULO CA conditions.
3. ULO reduced pear ripening overall while still allowing a fully ripe product at the end of long-term storage.
4. High (5%) CO₂ storage atmospheres resulted in severe pithy brown core and CO₂-related flesh browning but reduction or even control of superficial scald and black speckling.
5. Higher storage temperature (33 °F) resulted in less CO₂-related flesh browning but greater scald and black speckling incidence.
6. Considering storage O₂ levels and storage duration is critical for determining post-CA storage 1-MCP dose to reduce ripening and scald while still retaining ripening capacity.
7. Increased levels of naturally occurring chemicals in pear peel and cortex were observed in fruit at risk of superficial scald and pithy brown core before symptoms developed.

METHODS

Equipment and Cooperative Summary: Fruit quality assessment was performed at WSU TFREC and ARS - TFRL. Fruit chemistry analyses using analytical instrumentation (gas and liquid chromatography-mass spectrometry), and tissue cryopreservation were performed using facilities at ARS - TFRL in Wenatchee. Storage experiments were conducted in ARS - TFRL, Wenatchee in-house CA chambers and storage facilities.

Outreach: Aside from reports to the WTFRC, new information will be disseminated through presentations at industry meetings and at professional conferences, and by publications in industry publications and peer-reviewed journals.

Objective 1. Identify temperature and atmospheric storage combinations that reduce superficial scald without causing or exacerbating other disorders.

Year 1. d'Anjou pears were harvested from 3 orchards (Cashmere, WA; Dryden, WA; Hood River, OR) at commercial maturity. Pears were transported to the Tree Fruit Research Laboratory, sorted, analyzed for maturity, and placed storage atmospheres comprising 0.5% CO₂ and 0.5, 1.0, or 1.5% O₂ at 31 °F, 33 °F, or 37 °F. Each combination was initially represented by 72 pears. Pear quality and maturity (imaged, firmness, soluble solids, TA, ethylene production, internal and external appearance) were analyzed at 3, 6, and 8 months. The remainder of the pears were placed in a simulated post-storage cold chain where they were stored in air at 33 °F for an additional 4 weeks, assessing quality and maturity immediately upon removal as well as following 7 days at 68 °F. The evaluation after 8 months of CA storage simulates conditions during distribution and the resulting quality on the retail display/consumer table.

Year 2. d'Anjou pears were harvested from the Cashmere orchard 1 week prior to, at commercial maturity, and 1 week following commercial maturity. The same storage conditions and evaluations were performed as in year 1.

Year 3. As superficial scald and browning disorders can be influenced by location, in year 3, d'Anjou pears were harvested from 9 different orchards (Hood River, OR; Dryden, WA; Yakima, WA;

Orondo, WA; Cashmere, WA (4); White Salmon, WA) at commercial maturity. Pears were transported to the Tree Fruit Research Laboratory, sorted, analyzed for maturity, and placed in controlled storage atmospheres comprising 0.5% O₂ and either 0.5 or 5% CO₂ at 31 °F or 33 °F. Each combination was initially represented by 144 pears per location. Fruit were removed from CA after 8 months of storage and run through a simulated post-storage cold chain where they were stored at 33 °F for an additional 4 weeks, then 7 days at 68 °F. Quality and maturity were assessed upon removal from CA, 33 °F storage, and after 7 days at 68 °F.

Objective 2. Determine what post-storage ripening and scald controls can be used following ultra-low oxygen (ULO) controlled atmosphere (CA).

Year 1. d'Anjou pears were harvested from an orchard near Cashmere at commercial maturity, transported to the Tree Fruit Research Laboratory, sorted, and harvest maturity/fruit quality analyzed. To test the impact of delayed 1-MCP treatment on ripening capacity, pears were treated at harvest with 150 ppb 1-MCP for 12 h in air, then placed in ULO CA (0.5% O₂: 0.5% CO₂), or treated with 1-MCP in the same fashion after 0.5 or 1 month ULO CA storage. Pears were stored under these conditions for 8 months. At 8 months, a subset of these were treated with 150 ppb 1-MCP as indicated. Pear fruit quality and maturity (image, firmness, soluble solids, TA, ethylene production, internal and external appearance) was analyzed, and fruit was placed in a simulated post-storage cold chain where they were stored in air at 33 °F for an additional 4 weeks, evaluating quality and maturity immediately upon removal as well as following 7 days at 68 °F.

Year 2. In Year 2, 1 ppm and 150 ppb were applied for post-CA storage 1-MCP treatment on pears from the Cashmere orchard.

Year 3. In year 3, pears from the Cashmere orchard were placed immediately in CA comprising 0.5% CO₂ and 0.2, 0.5, or 1.0% O₂ at 31 °F. After 8 months of storage in CA, half of the pears were treated with 1000 ppb 1-MCP while the other half remained untreated as a control. Pears from the same orchard were stored in 0.5% O₂ and 0.5% CO₂ at 33°F for Objective 1. After 2, 4, and 6 months of storage, a subset was removed from CA. Half of each subset was treated with 1000 ppb 1-MCP while the other half remained untreated for control. In both experiments, fruit quality and maturity were evaluated after removal from CA storage and throughout a simulated post-storage cold chain as in previous years.

Objective 3. Evaluate tests that indicate disorder control effectiveness during ULO CA.

Year 1. Peel and cortex of a subset of pears stored at different temperatures and O₂ percentages from the Cashmere orchard in Objective 1 were sampled at 0, 1, 3, 6, and 8 months to track changes in levels of natural chemicals associated with disorder risk in apples and pears. Tissue was processed, stored, and analyzed using 3 in-house analyses for natural chemicals, including those associated with superficial scald (apples and pears), CO₂ sensitivity (apples), and soft scald/soggy breakdown (apples). These analyses also include those directed towards confirming links between pithy brown core and natural peel chemicals in an earlier study.

Year 2. The same experiment was repeated in year 2.

Year 3. In year 3, peel and cortex of a subset of pears from each of the 9 orchards stored at different temperatures and O₂ percentages from the Cashmere orchard in Objective 1 were sampled at 3, 6, and 8 months to track changes in levels of natural chemicals associated with disorder risk in apples and pears. Tissues are being processed, stored, and analyzed using 3 in-house analyses for naturally occurring chemicals as in previous years.

RESULTS AND DISCUSSION

ULO storage (0.5% O₂) can reduce or control superficial scald of d'Anjou pears.

ULO atmospheric conditions (0.5% O₂, 0.5% CO₂) of d'Anjou pears reduced or controlled superficial scald incidence after 8 months of storage followed by a simulated cold chain (4 weeks in 33 °F air followed by 7 days in 68 °F) in year 1 and 2. In year 1, almost no superficial scald was observed in pears stored at 0.5% O₂, despite coming from two different orchards (Figure 1). Pears stored at 1.0 or 1.5% O₂ developed significant scald. While incidence was slightly at higher temperatures, but it appears oxygen levels during storage had the greatest impact on disorder development. Similarly, in year 2, pears harvested from Cashmere, WA, and stored in 0.5% O₂ had significantly less superficial scald than those stored at 1.0 or 1.5% O₂ (Figure 2). For this experiment, pears that were more mature at harvest, or stored at 33 °F, had slightly higher incidence of scald.

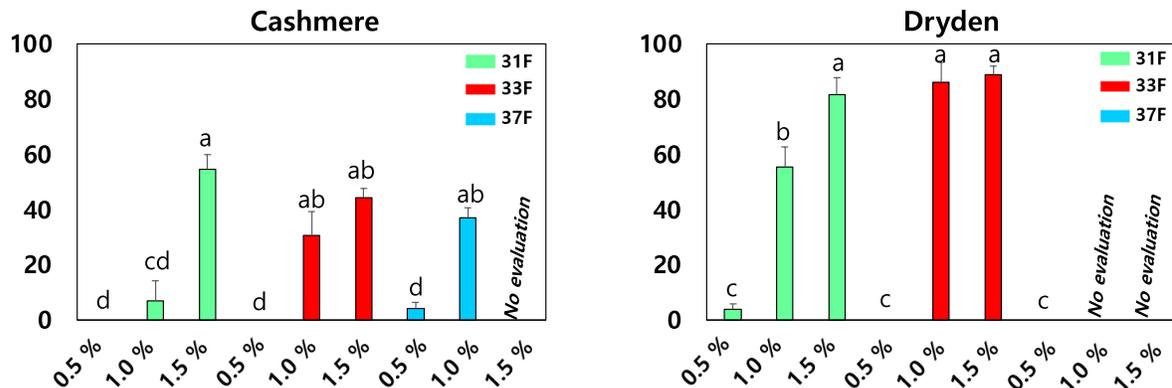


Figure 1. Percent superficial scald incidence in d'Anjou pears from two orchards in year 1 after 8 months of CA storage with a range of O₂ levels and temperature combinations, followed by 4 weeks of storage at 33 °F, and 7 days at 68 °F. Superficial scald was significantly lower on pears stored at 0.5% O₂. A third orchard in Hood River did not develop scald. 'No evaluation' for pears stored at 37 °F was due to loss from Mucor rot and secondary infections. Different lowercase letters indicate significant differences between treatments according to a z-test ($p \leq 0.05$).

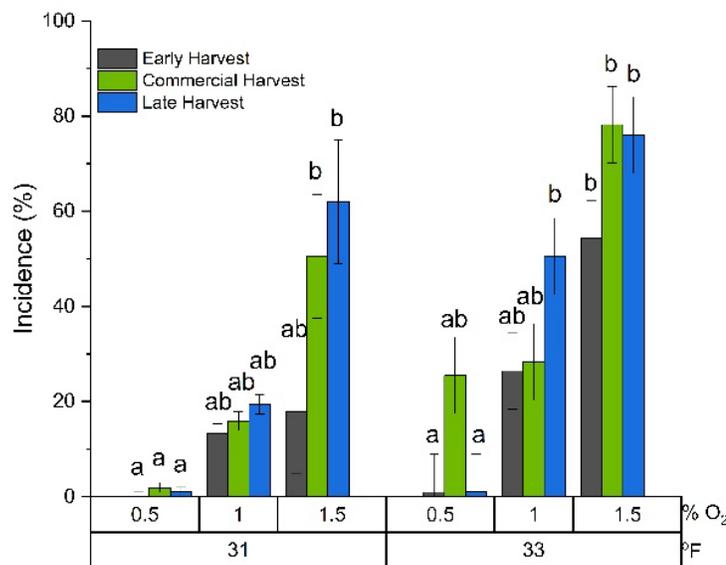


Figure 2. Superficial scald incidence in d'Anjou pears harvested from Cashmere, WA. (A) Pears harvested at different maturities in year 2 and stored in a range of O₂ levels and temperature combinations, followed by 4 weeks of storage at 33 °F, and 7 days at 68 °F. Different lowercase letters indicate significant differences between treatments according to a z-test ($p \leq 0.05$).

In year 3, we observed similar trends between oxygen and temperature regarding scald incidence. Four of the 9 orchards developed superficial scald after long term storage (8 months plus cold chain), and incidence was higher on fruit stored at 33 °F when compared with 31 °F (Table 1). Links between relative harvest maturity among orchards and scald incidence were not apparent. This experiment also sought to determine the impact of high (5.0%) CO₂ during on fruit quality and disorder incidence at both temperatures. Fruit from orchard 5 was used in year 3 for Objective 2 activities (see below) where no superficial scald developed following 2, 4, or 6 months storage or during the cold chain thereafter; however, scald developed on fruit stored for 8 months in 1.0% O₂ atmospheres (not shown).

Table 1. Superficial scald incidence in d’Anjou pears from 9 orchards in WA and OR in year 3. Values represent percent incidence after 8 months of CA storage and a simulated cold chain (4 weeks in 33 °F air followed by 7 days in 68 °F). In orchards with fruit susceptible to scald, 5% CO₂ storage atmosphere prevented development regardless of temperature. Different lowercase letters indicate significant differences between treatments according to a z-test ($p \leq 0.05$).

Orchard	31 °F		33 °F		CO ₂
	0.5%	5.0%	0.5%	5.0%	
1	22.2 b	0 a	64.3 c	1.4 a	
2	1.5 a	0 a	0 a	0 a	
3	0 a	0 a	0 a	0 a	
4	20.4 b	3.9 a	21.9 b	0 a	
5	2.8 a	0 a	0 a	0 a	
6	1.4 a	0 a	50.7 bc	1.4 a	
7	1.5 a	0 a	0 a	0 a	
8	6.3 a	1.6 a	1.6 a	0 a	
9	0 a	0 a	19.0 b	0 a	

When it occurred, post-storage black speckling was lower in high CO₂ environments.

Black speckling, a physiological disorder of d’Anjou pears characterized by dark brown to black spots that form a dendritic-like pattern in the top layers of peel tissue, developed on pears from a few orchards in year 3. As in earlier studies, black speckling symptoms developed after 8 months of storage similar to superficial scald. Also similar to superficial scald observed in the same sample populations, black speckling developed mostly on fruit stored at 33 °F in most cases; however, the relationship between disorder incidence and temperature is not as clear or consistent as with superficial scald (Table 2). As with superficial scald, storing fruit at 5% CO₂ prevented or otherwise resulted in significantly less (or no) disorder development. **Long-term storage of pears at 5% CO₂ is not recommended due to the significant amount of pithy brown core and internal browning, as described below (Figures 4 and 5).**

Table 2. Black speckling incidence on d’Anjou pears from 9 orchards in WA and OR in year 3. Values represent percent incidence after 8 months of CA storage and a simulated cold chain (4 weeks in 33 °F air followed by 7 days in 68 °F). Different lowercase letters indicate significant differences between treatments according to a z-test ($p \leq 0.05$).

Orchard	31 °F		33 °F		CO ₂
	0.5%	5.0%	0.5%	5.0%	
1	0 a	0 a	0 a	0 a	
2	0 a	0 a	0 a	0 a	
3	0 a	4.3 ab	20.6 bc	0 a	
4	13.0 ab	0 a	15.6 abc	0 a	
5	0 a	0 a	2.8 ab	0 a	
6	0 a	0 a	0 a	0 a	
7	4.5 ab	0 a	13.4 ab	11.8 ab	
8	31.3 c	3.2 ab	30.2 c	4.7 ab	
9	6.1 ab	0 a	0 a	4.8 ab	

ULO stored pears retained quality and ripening capacity after 8 months.

When developing storage conditions for disorder management, we must also consider the quality of the fruit throughout storage, handling, distribution, and final eating quality. ULO conditions slow fruit metabolism, helping to maintain firmness throughout storage. In our experiments, we found that ULO-stored pears retained firmness throughout the entire cold chain until moved to room temperature (68 °F for 7 days). In year 3, pears from 9 different orchards stored under different ULO atmospheric also retained firmness until transfer to room temperature, eventually ripening 3lbs pressure regardless of CO₂ level or temperature (Figure 3). In previous years, relative harvest maturity of successively harvested pears influenced softening, with more mature fruit less likely to remain firm during the cold chain. Storage temperature had less of an influence on softening, with the exception of pears stored at 37 °F that did not maintain firmness during CA storage. No clear relationship was observed among storage conditions for pears harvested from the 9 orchards used in year 3.

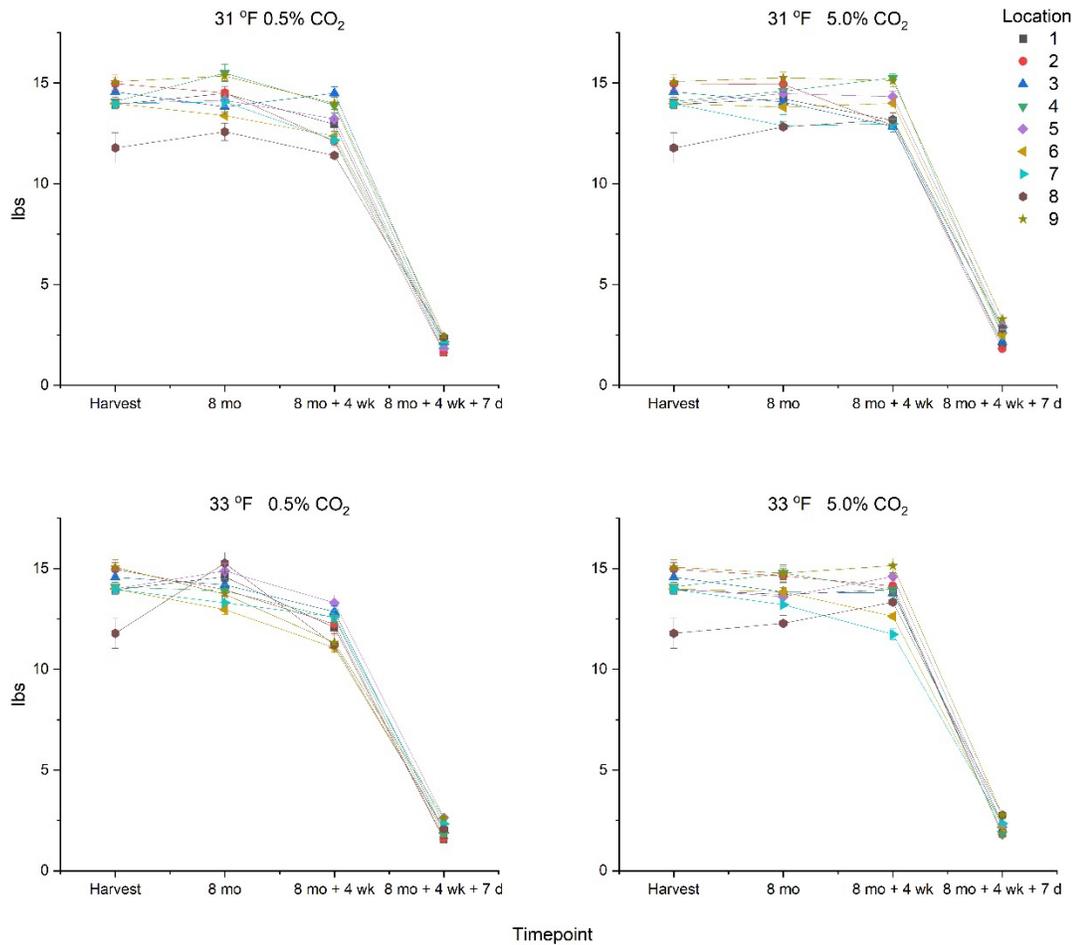


Figure 3. Firmness of d’Anjou pear firmness harvested from 9 different orchards in year 3 between harvest and throughout the simulated cold chain. (Note: x-axis is not to scale.) All pears were stored in ULO (0.5% O₂) and either 0.5 or 5.0% CO₂, and 31 or 33 °F. Pears maintained firmness until transferred to 68 °F, where pears ripened regardless of storage regime. Bars at each data point represent standard error.

Pithy brown core and internal browning incidence increased with CO₂ levels and decreased with storage temperature.

In our original hypothesis, we expected the combination of low temperatures and ULO storage atmospheres to result in higher incidence of internal disorders, including pithy brown core. What we observed in the first year was that fruit from 2 of 3 different orchards stored at higher temperatures developed higher pithy brown core incidence by the end of the 8-month storage and cold chain simulation. This was especially true for the fruit from Hood River, which showed no meaningful correlation to O₂ levels (Figure 4). Pithy brown core was not observed in any fruit during year 2 experiments. Observations from the first 2 years suggest risk for pithy brown core risk is associated with location.

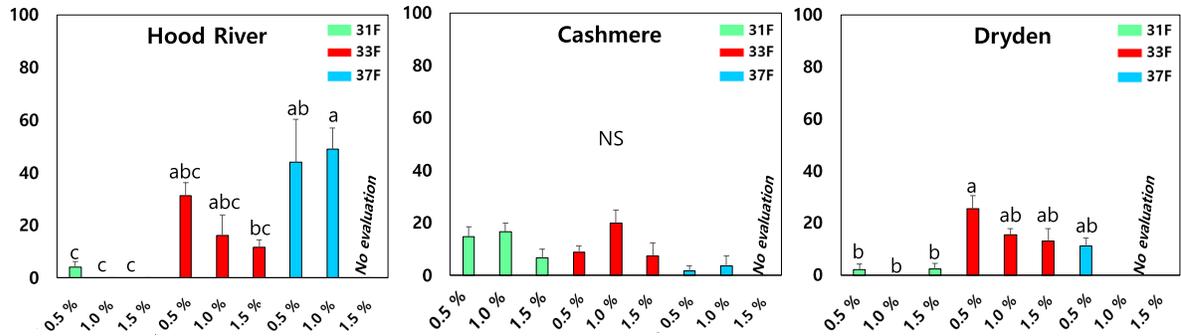


Figure 4. Pithy brown core incidence of d’Anjou pears harvested from 3 orchards following 8 months storage under variable O₂ (0.5% CO₂) and temperature conditions followed by 4 weeks at 33 °F and 7 days at 68 °F. Pithy brown core was reduced by lower temperature or remained the same in pears from 2 orchards. Pears stored at 37 °F were lost to primarily mucor rot and could not be evaluated. Different lowercase letters indicate a difference among treatment according to a z-test ($p \leq 0.05$).

In year 3, d’Anjou pears were harvested from 9 orchards to determine the relationship between storage disorders and CO₂ sensitivity, which is often location specific. Pears were stored in 0.5% O₂ with 0.5 or 1.5% CO₂ and 31 or 33 °F for 3, 6, or 8 months followed by a simulated cold chain. Previous studies with d’Anjou under these same storage conditions failed to produce any internal disorders; however, in this study, pithy brown core began appearing as early as 3 months. By the end of 8 months, pears from all orchards developed pithy brown core under 5% CO₂ conditions (Table 3). In some cases, CO₂ injury extended into the cortex (Table 4) placing them at higher risk of culling. Results of this experiment align with many previous studies that support that CO₂ sensitivity to be orchard specific. Unlike the experiment in year 1, the relationship between temperature and pithy brown core and CO₂ injury is not as clear with fruit stored in 0.5% CO₂, further highlighting the influence of location and year-to-year variability.

Table 3. Percent incidence of pithy brown core in d’Anjou pears from 9 different orchards. Pears were stored under ULO (0.5% O₂) and 0.5 or 5% CO₂, in 31 or 33 °F for 8 months, followed by a simulated cold chain (4 weeks in 33 °F air followed by 7 days in 68 °F). Different lowercase letters indicate significant groups among treatments according to a z-test ($p \leq 0.01$).

Orchard	31 °F		33 °F		CO ₂
	0.5%	5.0%	0.5%	5.0%	
1	1.6 a	68.9 def	4.3 a	41.4 de	
2	1.5 a	60 de	9 abc	65.7 def	
3	40.0 de	39.1 de	17.6 bc	43.5 de	
4	7.4 ab	62.7 def	9.4 abc	50.8 de	
5	6.9 ab	38.6 cde	4.2 a	52.8 de	
6	0 a	50.7 de	0 a	4.2 a	
7	4.5 a	94.0 fg	14.9 abc	54.4 de	
8	1.6 a	41.3 de	6.3 ab	21.9 bcd	
9	1.5 a	71.9 ef	29.3 bcd	6.3 ab	

Table 4. CO₂-related browning incidence in d’Anjou pears harvest from 9 different orchards. Pears were stored under ULO (0.5% O₂) and either 0.5 or 5% CO₂ and 31 or 33 °F for 8 months, followed by 4 weeks in 33 °F air followed by 7 days in 68 °F. Different lowercase letters indicate significant groups among treatments according to a z-test ($p \leq 0.01$).

Orchard	31 °F		33 °F		CO ₂
	0.50%	5.0%	0.50%	5.0%	
1	0 a	45.9 de	0 a	15.7 abc	
2	0 a	5.7 ab	0 a	13.4 abc	
3	24.6 bc	23.2 bc	1.5 a	21.7 bc	
4	3.7 a	19.6 bc	1.6 a	16.9 abc	
5	0 a	17.1 abc	0 a	4.2 a	
6	0 a	27.5 bcd	1.4 a	0 a	
7	1.5 a	55.2 de	1.5 a	11.8 abc	
8	3.1 a	20.6 bc	6.3 ab	3.1 a	
9	0 a	28.1 bcd	1.7 a	0 a	

Post-CA storage 1-MCP dosage is governed by CA O₂ levels and storage duration to reduce scald incidence and ripening of d’Anjou pears.

In year 1, low-rate applications of 1-MCP (150 ppb) were applied at harvest and after 1, 2, and 8 months in CA comprising 0.5% O₂ and 0.5% CO₂ at 31 °F. The early applications resulted in fruit that did not ripen, and the 8-month application had no impact when compared to the control throughout the remainder of the cold chain. In that season, scald was controlled on pears from that orchard using ULO conditions. To provide a starker contrast for the efficacy of 1-MCP, in year 2 pears from Hood River stored for 8 months in 1.0% O₂ and 0.5% CO₂ CA storage at 33 °F were treated with 150 ppb or 1000 ppb 1-MCP after CA storage. Following treatment, pears were transferred to and held for a 4 or 8-week cold chain at 33 °F followed by 7 days of ripening at 68 °F. Results show both doses of 1-MCP sufficiently controlled scald in the 4-week cold chain; however, 100% of pears treated with 150 ppb 1-MCP developed superficial scald by the end of the 8-week cold chain (Figure 5). By contrast, 50% of pears treated with 1000 ppb 1-MCP had scald by the end of the 8-week cold chain. Additionally, pears treated with 150 ppb softened more quickly during the cold chain than those treated with 1000 ppb (Table 5). By the end of the ripening periods, all fruit were at an acceptable firmness. Though the pears treated with 1000 ppb might need more than 7 days to ripen after a 4-week cold chain without other ripening treatments, results show that both treatments of 1-MCP applied after long-term storage allow full ripening.

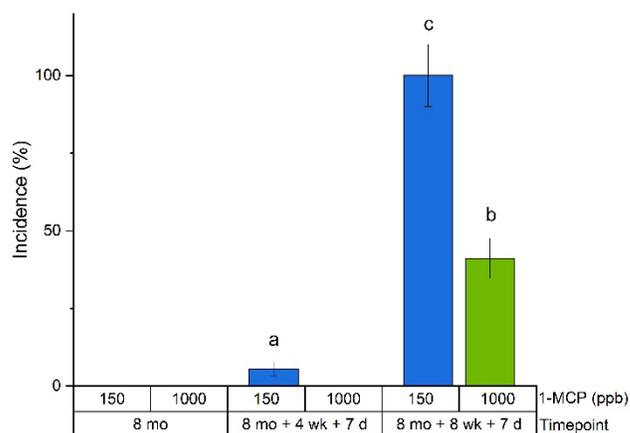


Figure 5. Superficial scald incidence on d'Anjou pears following 8 months of ULO CA storage followed by treatment using either 150 ppb or 1000 ppb 1-MCP, then 4 weeks or 8 weeks at 33 °F and 7 days at 68 °F. Different lowercase letters indicate significant groups among treatments according to a z-test ($p \leq 0.05$).

Table 5. Firmness of d'Anjou pears following ULO CA storage (0.5% O₂; 0.5% CO₂) and rates of 1-MCP. 1-MCP at a rate of 1000 ppb, but not 150 ppb, improved the scald/quality outcome. Evaluations were conducted during 4 or 8 weeks of air storage at 33 °F (4 or 8 wk) and 7 days at 68 °F (7 d) following ULO CA storage (8 mo). Letters indicate significant differences in firmness according to SAS proc glm ($p \leq 0.05$).

1-MCP (ppb)	Firmness (lbs)				
	8 mo	8 mo + 4 wk	8 mo + 4 wk + 7 d	8 mo + 8 wk	8 mo + 8 wk + 7 d
150	13.06 a	7.93 b	1.70 d	6.81 b	1.77 d
1000	12.83 a	13.09 a	3.50 c	12.14 a	1.58 d

In year 3, d'Anjou pears from a single orchard in Cashmere, WA, were used to test 1000 ppb 1-MCP application after 2, 4, or 6 months of storage in 0.5% O₂ and 0.5% CO₂ at 33 °F (Table 6). None of the pears in this experiment developed scald or internal disorders by the end of the cold chain and ripening periods, however, these disorders are typically seen closer to 8 months of storage and after. It is important to note the 1000 ppb 1-MCP treated pears did not fully ripen by the end of each cold chain and ripening period. Softening and ethylene production during ripening at room temperature indicates 1-MCP treated pears would eventually ripen to eating quality but would require more than the standard 7 days at 68°F or other heat/ethylene-based d'Anjou ripening protocol. Nonetheless, post-storage treatment was effective. Pears from the same orchard were used to test post-storage application of 1000 ppb 1-MCP on fruit stored in 0.2, 0.5, or 1.0% O₂ and 0.5% CO₂ at 31 °F for 8 months. Pears stored in 1.0% O₂ developed superficial scald regardless of 1-MCP concentration, but ULO conditions effectively controlled the disorder (Figure 6). By the end of the ripening period, all untreated pears had softened, whereas 1-MCP treated pears softened less as storage O₂ levels decreased with pears stored in 0.2% O₂ ripening least (Table 7). Based on these results, 1-MCP applied post-storage can help reduce the rate of softening and manage scald during shipping and handling. ULO alone or in combination with post-storage 1-MCP treatment can reduce superficial scald in certain conditions. **It is of the utmost importance when determining proper 1-MCP dosage to consider storage duration and CA O₂ levels as improper dosage may, at worst, result in pear that will not ripen.**

Table 6. Firmness of d’Anjou pears in year 3 after CA storage (0.5% O₂; 0.5% CO₂) for 2, 4, or 6 months followed by 1000 ppb 1-MCP application with a simulated cold chain and ripening period. None of the pears in this experiment developed superficial scald or internal disorders. Letters indicate significant differences in firmness according to SAS proc glm ($p \leq 0.05$).

		Firmness (lbs)		
1-MCP (ppb)		2mo	2mo + 4wk	2mo + 4 wk + 7d
0		15.58 a	14.94 a	2.55 d
	1000	15.02 a	14.26 a	13.09 ab
0	4mo	14.76 a	14.90 a	3.15 d
	1000	15.43 a	15.08 a	7.97 c
0	6mo	14.96 a	14.46 a	2.83 d
	1000	14.21 a	13.53 ab	11.10 b

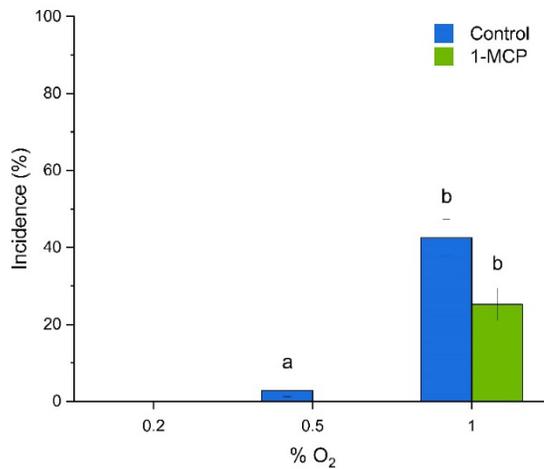


Figure 6 Superficial scald incidence of d’Anjou pears in year 3 following 8 months of CA storage with variable O₂ levels followed by treatment with 1000 ppb 1-MCP, then 4 weeks or 8 weeks at 33 °F and 7 days at 68 °F to simulate cold storage, distribution, and retail shelf time. Different lowercase letters indicate significant groups among treatments according to a z-test ($p \leq 0.05$).

Table 7 Firmness of d’Anjou pears in year 3 after CA storage with variable O₂ levels followed by treatment with 1000 ppb 1-MCP, then 4 weeks or 8 weeks at 33 °F and 7 days at 68 °F to simulate cold storage, distribution, and retail shelf time. Letters indicate significant differences in firmness according to SAS proc glm ($p \leq 0.05$).

		Firmness (lbs)		
O ₂		8mo	8mo + 4wk	8mo + 4wk + 7d
Control	0.20%	13.61 a	11.51 b	2.01 c
	0.50%	12.42 b	11.69 b	2.15 c
	1.00%	13.28 a	11.17 b	1.91 c
1000 ppb 1-MCP	0.20%	13.55 a	12.76 a	11.40 b
	0.50%	13.00 a	12.73 a	6.81 d
	1.00%	13.61 a	12.24 b	3.35 c

Increased levels of naturally occurring chemicals in pear peel and cortex were linked to risk of superficial scald and pithy brown core before symptoms developed.

Conjugated trienol (CTOL) levels increased with superficial scald risk in pear peel prior to symptom development. The highest levels at 1-8 months (prior to symptom development) were produced by pears stored in the highest O₂ levels (Figure 7). CTOL levels estimated in peel from pears stored in 0.5% O₂ changed the least compared with the initial values (typically undetectable in apple or pear peel before storage). An analysis protocol for this natural chemical to determine superficial scald risk in apple peel has been published (Blakey and Rudell, 2017) and is currently in use by some regional apple producers. We have subsequently identified another class of compounds, phytosterols, that are associated with changes in plant cellular membranes (the envelopes holding cell components in the correct place that must remain fluid at all temperatures). Phytosterols were identified earlier in association with superficial scald of apples and pears and, more recently, with soggy breakdown and CO₂-related disorders of apple. Links with a ratio of 2 of the phytosterols (ASG/SE) increased in peel with O₂ percentage, as did scald incidence. However, the link was not as clear with regard to temperature in pears stored at 37 °F which had a low ratio compared with those stored at lower temperatures, yet similar scald incidence (Figure 8). Our continuing analyses will focus on Year 3 data where substantial incidence of pithy brown core and internal browning has developed, providing prime contrasts to determine whether monitoring these natural chemicals yields potentially actionable information regarding superficial scald or CO₂-sensitivity risk.

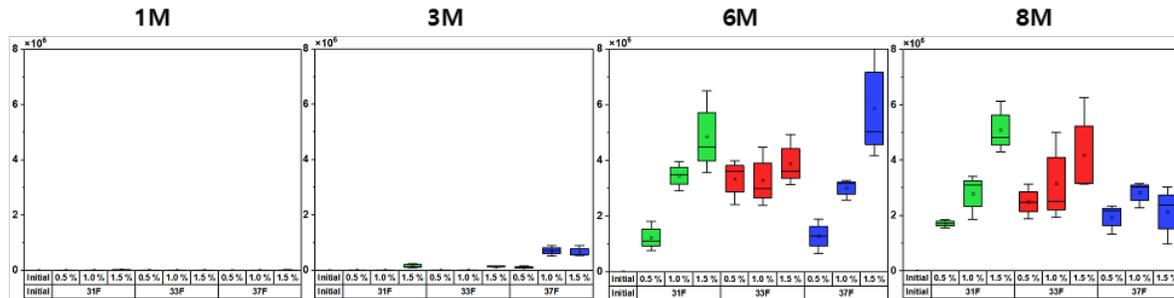


Figure 7. Accumulation of conjugated trienol (CTOL) in peel of d’Anjou pears harvested from Cashmere, WA and stored in 0.5% CO₂ plus 0.5%, 1%, or 1.5% O₂ at 31, 33, or 37 °F. CTOL accumulation is associated with the environmental conditions that cause superficial scald. Results here reflect the final scald incidence presented for this orchard in Figure 1. Error bars represent standard deviation.

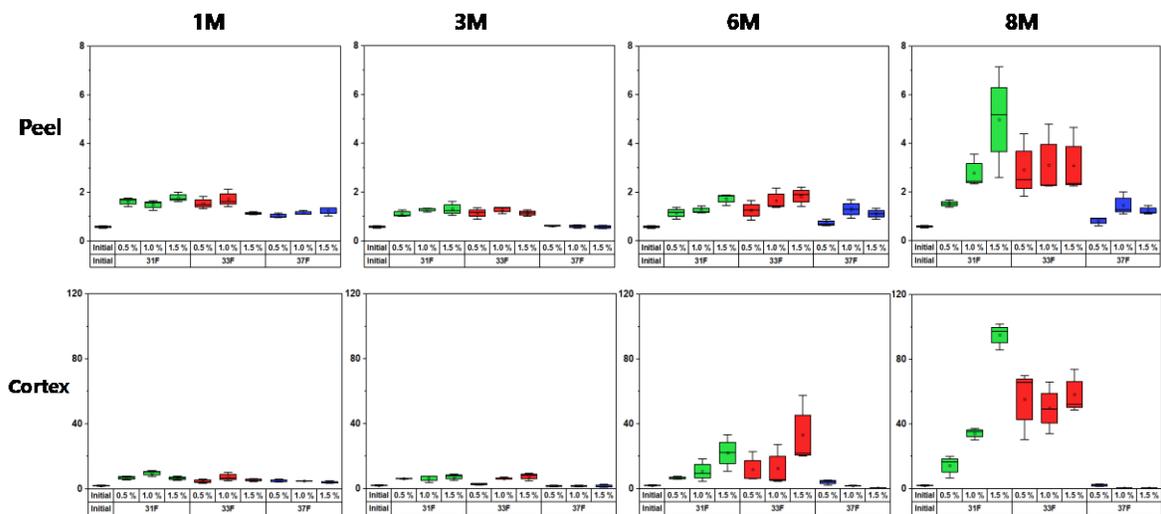


Figure 8. Changes of the ASG to SE ratio in peel and cortex of d'Anjou pears harvested from Cashmere, WA and stored in 0.5% CO₂ plus 0.5%, 1%, or 1.5% O₂ at 31, 33, or 37 °F. Elevated ASG/SE in peel is associated with superficial scald in apple and, in cortex, with soggy breakdown and CO₂-related browning also in apple. Results here reflect the final scald incidence presented for this orchard in Figure 1. Error bars represent standard deviation.

Project Title: Ultra-low O₂ CA strategies to reduce 'd'Anjou' storage disorders

Executive Summary

Keywords: pear, CO₂, superficial scald, cold chain, pithy brown core

Abstract: With diminishing market acceptability of ethoxyquin, new tools and strategies are required to control d'Anjou superficial scald that do not have negative impacts on eating quality. We evaluated combinations of ULO CA storage, storage temperatures, and post-storage 1-MCP treatment with the expectation of controlling superficial scald at warmer storage temperatures without consequential CO₂-related disorder or black speckling incidence. Superficial scald was reduced or controlled by ULO CA depending in most cases. Pithy brown core and internal browning were particularly severe in Year 3 when pears were stored in elevated CO₂ (0.5% O₂; 5% CO₂). Black speckling also developed on pears from some orchards in Year 3. Incidence of both black speckling and superficial scald was suppressed by atmospheres comprising elevated CO₂. Warmer storage temperatures resulted in poorer scald and black speckling control but improved pithy brown core and internal browning reduction. Post-CA storage 1-MCP treatment, considering CA O₂ levels and storage duration for dosage, both reduced scald and ripening while pears still retained ripening capacity. Results highlight further guidelines to use ULO in crop protectant restricted cold chains or post-storage 1-MCP treatment to suppress quality loss while retaining ripening capacity.

Project Outcomes:

1. Expectations for employing ULO alone to reduce or control d'Anjou superficial scald.
2. Understanding of temperature and high CO₂ impacts on controlling scald, black speckling, and CO₂-related disorders using ULO CA.
3. Necessary considerations for effective post-storage 1-MCP for quality control.

Significant Findings:

1. ULO storage (0.5% O₂) reduces or controls superficial scald of d'Anjou pears.
2. Black speckling developed on some orchards in one season in ULO CA conditions.
3. ULO reduced pear ripening overall while still allowing a fully ripe product at the end of long-term storage.
4. High (5%) CO₂ storage atmospheres resulted in severe pithy brown core and CO₂-related flesh browning but reduction or even control of superficial scald and black speckling.
5. Higher storage temperature (33 °F) resulted in less CO₂-related flesh browning but greater scald and black speckling incidence.
6. Considering storage O₂ levels and storage duration is critical for determining post-CA storage 1-MCP dose to reduce ripening and scald while still retaining ripening capacity.
7. Increased levels of naturally occurring chemicals in pear peel and cortex were observed in fruit at risk of superficial scald and pithy brown core before symptoms developed.

Future Directions:

1. Determine if short low O₂ stress treatments reduce or control superficial scald without increasing black speckling, pithy brown core, or internal browning.
2. Determine if short high CO₂ treatments at the beginning of long-term storage reduce superficial scald, black speckling without increasing PBC and internal browning incidence.
3. Contributions of water condensation on pear surface to the development of black speckling symptoms.
4. Continued focus on above freezing storage temperatures.
5. Continued focus on best practices for post-CA 1-MCP treatment to reduce superficial scald and manage ripening during distribution.