

2026 NW Pear Research Review



Tory Schmidt (WTFRC) discusses chemical thinning experiments at the Cashmere site with local growers and Dutch guests during a pear field day. (July 2025)

Photo Source: Raesibe Kgaphola

February 19, 2026

**Hybrid Format
Wenatchee, WA**

Title: New controlled atmosphere strategies to extend ‘Bartlett’ pear storage

Report Type: Continuing project report (Year 2, no cost extension)

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Cooperators: Pear packinghouses in the Columbia River Gorge vicinity, Dr. Yu Dong, Janet Turner, Shawn McMurtrey, Emmi Klarer, Christopher Imler

Project Duration: 2-year

Total Project Request for Year 1 Funding: \$ 99,276 (received)

Total Project Request for Year 2 Funding: \$ 104,163 (received)

Other related/associated funding sources: Awarded

Funding Duration: 2024 - 2025

Amount: \$95,000

Agency Name: USDA-ARS TFRL

Notes: 0.5 FTE, Biological Science Technician, GS-9 step 2, 3, salary and benefits; supplies and equipment

WTFRC Collaborative Costs: none

Budget 1

Primary PI: Rachel Leisso*

*This budget also includes funds for David Rudell, Loren Honaas, and James Mattheis as these PIs belong to the same administrative unit; see footnotes for details.

Organization Name: USDA-ARS TFRL

Contract Administrator: Mara Guttman

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Station Manager/Supervisor: James Mattheis

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Item	2023	2024
Salaries	\$48,505.00	\$50,131.00
Benefits	\$19,655.00	\$20,716.00
Wages		
Benefits		
RCA Room Rental	\$5,570.00	\$5,570.00
Shipping		
Supplies	\$5,000.00	\$5,000.00
Travel	\$500.00	\$2,500.00
Plot Fees	\$1,250.00	\$1,250.00
Miscellaneous	\$10,000.00	\$10,000.00
Total	\$90,480.00	\$95,167.00

Footnotes:

Salaries: 1.0 FTE Biological Science Technician (GS-7), plus ~15 hours of overtime, annually.

Benefits: For Biological Science Technician (GS-7)

RCA room rental: per OSU-MCAREC fee book (cost per sq ft x time) (2 rooms, one with experimental CA chambers)

Supplies: harvest and storage supplies, reagents, and consumables for aroma profiling (Rudell and Leisso)

Travel: fruit transport locally and between Hood River and Wenatchee for fruit storage

Plot fees: 0.25-acre rental, OSU-MCAREC

Miscellaneous: sequencing (Honaas)

Budget 2

Co PI 2: Achala KC

Organization Name: OSU Ag. Res. Foundation

Contract Administrator: Josh Kvidt

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Station Manager/Supervisor: Richard Roseberg

Station manager/supervisor email address: richard.roseberg@oregonstate.edu

Item	2023	2024
Salaries	\$4,167.00	\$4,292.00
Benefits	\$2,629.00	\$2,704.00
Wages		
Benefits		
RCA Room Rental		
Shipping	\$500.00	\$500.00
Supplies	\$500.00	\$500.00
Travel	\$1,000.00	\$1,000.00
Plot Fees		
Miscellaneous		
Total	\$8,796.00	\$8,996.00

Footnotes: 1: Salaries for a Faculty Research Assistant @ \$50,000/year for 1 month, and 63.1% benefit rate. The FRA is expected to assist with inoculum preparation and isolation for rot related data, data collection, and analysis. 2: Shipping will consist of inoculum or fruit shipping during the study period between southern Oregon and Hood River. 3: Supplies for pathogen isolation and culture, as well as the harvesting supplies. 4: Travel between southern Oregon and Hood River for rot evaluation/rot related data collection.

Objectives

1. Evaluate ultra-low oxygen in comparison to other controlled atmosphere (CA) regimes for long-term 'Bartlett' storage.
2. Determine optimum maturity for long-term CA storage for Bartlett.
3. Evaluate the influence of modified atmosphere packaging (MAP) (LifeSpan, Amcor, Australia) on fruit quality post long-term CA storage.

Significant Findings

1. Bartlett stored in ultra-low (ULO) O₂ atmospheres (0.5 or 0.8% O₂; 0.5 % CO₂; 30 °F) ripened less, ultimately retaining quality and finish without browning symptoms while fully ripening once moved to warmer temperatures.
2. Higher O₂ CA settings resulted in more core browning during storage and senescent peel browning following storage.
3. Pears harvested at the earliest date ripened less during storage but developed superficial scald.
4. Pears stored in MAP (LifeSpan™) liners following long term CA storage ripened less were of higher quality, even at higher temperatures.
5. 1-MCP from sachets accumulated more in MAP bags but did not impact ripening or quality of pears previously stored in conventional CA conditions.

METHODS

Materials and Equipment

Controlled atmosphere. ARS (Hood River) controlled atmosphere conditions was maintained in a custom constructed cabinets served by automated controls (Empire Control Systems, Chelan, WA). Nitrogen (Shiflett's Inc, East Wenatchee, WA) and compressed air were generated at both worksites, and CO₂ is supplied using compressed gas cylinders.

Fruit quality evaluation (Hood River). Green color and relative loss of green color was determined by a handheld digital meter (DA meter; Sintelesia, Bologna, Italy). Flesh firmness was quantified using a fruit texture analyzer (FTA, Güss Manufacturing Ltd, Strand, South Africa). Soluble solids content (SSC) readings were measured from fruit juice samples expressed from fruit (excluding core tissue and seeds) via a juicer (Champion Classic 2000 Juicer, Plastaket Manufacturing Inc., Lodi, CA, USA) with a hand-held digital refractometer (HI 96822; HANNA Instruments, Smithfield, RI, USA). pH and titratable acidity were determined on a potentiometric titrator (Mettler-Todelo, Columbus, OH, USA). Fruit were visually rated for senescent scald (peel) and senescent core breakdown (flesh); defect rating scales are indicated in table footnotes.

MAP bags. The modified atmosphere bags are LifeSpan brand (Amcor, Inc., Zurich, Switzerland). Use of a particular product does not imply endorsement by the USDA-ARS.

Ethylene, CO₂, and O₂ evaluations. Ethylene, 1-MCP, and CO₂ gas samples (0.5 mL) were injected in a gas chromatograph-flame ionization detector (model 8890, Agilent Technologies, Santa Clara, CA, USA) equipped with a multimode inlet (MMI) (Agilent Technologies), Porabond Q column (Agilent CP7350, 10 m x 320 µm x 5 µm) connected in series to a thermal conductivity detector (TCD) and flame ionization detector (FID). Oxygen samples from a static headspace were pumped (Gas Sampling Sensor Micro Pump kit, GasLab.com, Ormond Beach, FL) through an infrared type sensor (LOX-O2-F coupled MX300 chip, GasLab.com) and reported to software (Gaslab 2.1, Gaslab.com).

1-MCP sachet application. 1-MCP sachets (0.014%; Agrofresh, Inc.) were wetted prior placing inside boxes. 1-MCP emission from sachets was verified both in sealed jars prior to experimentation as well as in-box after application.

Objective 1. Evaluate ultra-low oxygen in comparison to other controlled atmosphere (CA) regimes for long-term ‘Bartlett’ storage.

2025-2026 activities: **Activities assess the possibility of using ULO to extend Bartlett pear cold chain up to 10 months (total) as well as tolerance to O₂ setpoints as low as 0.2%.** Pears were acquired from commercial orchards in the Hood River area at commercial maturity. Pears were picked from bins, defective pears removed, and the remainder randomized to remove any bias contributed by bin layering. Firmness, color, soluble solids, titratable acidity, internal ethylene, and defects were evaluated to estimate harvest maturity and at-harvest quality. Pears were placed into 3 lugs (per treatment) containing 50 fruit each to be placed into CA chambers. Atmosphere settings include 0.2, 0.5, 0.8, and 2.0% O₂ (all <0.5 % CO₂; 31 °F). Fruit quality and relative ripeness will be evaluated immediately at 6 and 9 months and the remainder placed in boxes lined with perforated polyethylene liners to be stored at 31 °F in air for additional evaluations at 1 month and, then, following 1 week at 70 °F to ripen.

2024-2025 activities are detailed below in the Results and Discussion section.

Objective 2. Determine optimum maturity for long-term CA storage for ‘Bartlett’

2025-2026 activities: **Activity assesses the impact of harvest maturity on the capacity to produce high-quality Bartlett pears after 10 months in the cold chain.** Pears were harvested 3 times from the experimental orchard located on the MCAREC campus, Hood River. Each harvest is represented by sets of 3 trees with the air stored treatment taken from all trees in the test. Firmness, color, soluble solids, titratable acidity, internal ethylene, and defects were evaluated to estimate harvest maturity and at-harvest quality. The at-harvest firmness of Harvest 1 (8/4/25), Harvest 2 (8/11/25), and Harvest 3 (8/18/25) was 19.2, 17.9, and 16.6, respectively. 150 pears from each harvest were placed in a CA chamber containing only fruit from that harvest and the atmosphere adjusted to 0.5% O₂ and <0.5% CO₂ (31°F). The remainder of each harvest were stored at 31 °F in air in perforated polyethylene liners. Fruit quality and relative ripeness will be evaluated immediately at 6 and 9 months and the remainder placed in boxes lined with perforated polyethylene liners to be stored at 31 °F in air for additional evaluations at 1 month and, then, following 1 week at 70 °F to ripen.

2024-2025 activities are detailed below in the Results and Discussion section.

Objective 3. Evaluate the influence of modified atmosphere packaging (MAP) on fruit quality post long-term CA storage.

2025-2026 activities: **Activities will determine if MAP bags and/or post-storage 1-MCP (fumigation or sachets) will extend the cold chain following long term CA storage.** Bartlett pears will be acquired from packing sheds upon CA room opening to limit the time between removal and repackaging and treatment for the post-storage cold chain simulation. Three boxes lined with perforated polyethylene liners containing pears from each orchard/storage room will be treated with 1 ppm 1-MCP for 12 hours and another 3 using the label number/dose of 1-MCP sachets. Another 6 boxes lined with MAP bags will also undergo the same treatment regimen. Pears will be stored at 31°F for up to 8 weeks, evaluating quality and relative ripeness at removal from cold storage and after 7 days at 70 °F. Firmness, color, soluble solids, titratable acidity, internal ethylene, and defects were evaluated to estimate fruit quality.

2024-2025 activities are detailed below in the Results and Discussion section.

Results and Discussion

Objective 1. Evaluate ultra-low oxygen in comparison to other CA regimes for long-term ‘Bartlett’ storage.

Pears from each harvest were stored at USDA-ARS Hood River at 30 °F in the following CA conditions: 0.5% O₂, <0.5% CO₂; 0.8% O₂, <0.5% CO₂; 1.5% O₂, <0.5% CO₂; 2.5% O₂, <0.5% CO₂; Control fruit (no CA, Hood River only).

For Odell fruit, (harvested August 17), CA conditions were established one month after harvest. Parkdale fruit (harvested August 31) CA conditions were established two weeks after harvest. Initial fruit quality for both harvests is indicated in Table 1.

Table 1. Fruit quality seven days (Odell) and ten days (Parkdale) after harvest. Fruit were maintained in 30 °F air storage. No internal nor exogenous ethylene was detected for any fruit prior to establishing CA conditions.

Harvest date and location	Weight per fruit (g) ¹		I _{AD} (DA meter) ²		hue ³		Firmness (lbf)		Brix		TA	
Aug. 17, Odell	199	B	1.81	ns	114.3	A	17.1	ns	11.1	ns	0.34	A
Aug. 31, Parkdale	248	A	1.79	ns	113.1	B	16.7	ns	12.2	ns	0.20	B
<i>p</i> -value	0.0025		0.5536		0.0330		0.2999				0.0002	

1. Values in a column followed by different letters are statistically different at $p < 0.05$ (two-tailed t-test); not statistically different = ns.
2. DA meter; an indicator of green color (lower values indicate less green); for more information, see Hanrahan and Roder in References.
3. Hue, measured by colorimeter (Konica Minolta); lower values indicate less green color.

Fruit were removed from CA and quality/relative ripeness evaluated in February 2025 (~6 months; Table 2). For each evaluation, half of the fruit were evaluated for disorders immediately upon removal from cold (ripening day 0) and the other half after 7 days of ripening. I_{AD} (DA meter), colorimetry, and flesh firmness were evaluated on 18 fruit for each treatment and timepoint. Fruit stored at 0.5% O₂ generally had superior quality and lower senescent disorder incidence than fruit stored at higher O₂ regimes. No low-oxygen physiological disorders were observed.

Objective 2. Determine optimum maturity for long-term CA storage for ‘Bartlett’.

In August 2024, ‘Bartlett’ pears were harvested at Oregon State University, Mid-Columbia Research and Extension Center (OSU-MCAREC), Hood River, OR on 3 successive dates (Table 3). Goals for optimizing maturity for long-term storage of ‘Bartlett’ are defining optimal maturity and establishing the ideal method(s) for determining maturity. Trees were 15 years old at the time of harvest, on OHFx97 rootstock, and trained to a central leader. Commercial harvest timing was determined by a combination of the Hood River ‘Bartlett’ harvest maturity model (Chen, 2016), experienced fieldman recommendation, and flesh firmness. The first harvest (H1) on Aug. 6, 2024 (Table 3), was an ‘early’ harvest, with firmness at the time of harvest similar to high firmness fruit in University of California-Davis guidelines (Mitcham et al, 1996). The second harvest (H2), on Aug. 14, 2024, represented commercial harvest practices for standard CA conditions. The third harvest (H3), on August 21, was the “late” harvest, intended to represent fruit destined for earlier marketing, e.g. short-term CA or air storage. Based on firmness and size, these fruit were harvested earlier than a typical “late” harvest (Table 3). Harvested fruit were cooled, all harvests collected, and held for 2-4 weeks (depending upon the harvest timing) in air until USDA-ARS, Hood River CA storage was prepared (30 °F; 1.5% O₂, <0.5% CO₂). Beginning in January 2025, fruit were removed from CA to determine relative storage longevity in CA in relation to harvest timing.

Table 2. ULO CA reduces ripening and preserves quality better than higher O₂ setpoints. To determine the potential for ULO strategies to extend CA storage for ‘Bartlett’, four CA treatments were evaluated: 2.5% O₂, 1.5%O₂, 0.8% O₂, 0.5% O₂ and air (30 °F; Hood River worksite). For all CA treatments, CO₂ was maintained as low as possible. Relative ripeness was evaluated immediately following removal from CA storage after 5 months (day 0) and after 7 days of ripening at 70 °F.

Orchard location	O ₂ %	ripening (days)	I _{AD} (DA meter ²)	flesh firmness (lbf)	senescent scald incidence ³	senescent core breakdown incidence ³	senescent core breakdown severity
Odell	air	0	1.27 b	17.5 a	1 ns	47 a	1.5 a
	0.5%		1.69 b	16.3 b	0 ns	2 b	0.1 b
	0.8%		1.56 b	16.9 ab	0 ns	1 b	0.0 b
	1.5%		1.62 b	16.6 b	0 ns	3 b	0.1 b
	2.5%		1.55 a	17.5 b	0 ns	4 b	0.0 b
Odell	air	7	0.09	2.2	79 a	44 a	1.2 a
	0.5%		0.11	3.3	0 c	2 c	0.1 b
	0.8%		0.05	3.5	0 c	8 bc	0.2 b
	1.5%		0.13	3.8	0 c	13 b	0.2 b
	2.5%		0.07	2.2	6 b	5 bc	0.0 b
Park dale	air	0	1.18 d	16.4 a	0 ns	5 ns	0.0 ns
	0.5%		1.70 a	15.9 ab	0 ns	4 ns	0.2 ns
	0.8%		1.60 ab	15.7 ab	0 ns	1 ns	0.0 ns
	1.5%		1.38 c	15.4 b	0 ns	1 ns	0.0 ns
	2.5%		1.47 bc	15.1 b	1 ns	2 ns	0.1 ns
Park dale	air	7	0.31 a	7.5 a	57 a	37 a	1.2 a
	0.5%		0.11 c	3.4 bc	0 d	1 c	0.0 c
	0.8%		0.16 bc	2.9 c	0 d	1 c	0.0 c
	1.5%		0.27 ab	4.3 b	13 c	17 b	0.3 b
	2.5%		0.17 c	3.3 bc	40 b	13 b	0.4 b

Harvest maturity differences were most reflected by fruit weight, I_{AD} (DA meter), and firmness, while differences of hue, Brix, and titratable acidity were negligible (Table 3). Brix to firmness maturity ratios for H1 and H2 aligned with California recommendations for higher firmness harvests (Mitcham et al., 1996). Average “indirect chlorophyll or green color indicator” (I_{AD}, obtained by a DA meter) values were lower than optimal I_{AD} values established by Wang et al. (2015), whose results indicated that ‘Bartlett’ fruit harvested at I_{AD} 2.1 to 2.2 were optimal for long-term (3-month air) storage of ‘Bartlett’. There was also considerable variability in firmness in our study (data not shown) within each harvest, which has been documented in other studies, for example, Claypool (1973). This challenge may be addressed by ethylene conditioning (Villabos-Acuna and Mitcham, 2008). Results indicated that earlier harvests ripened less during storage and developed less senescence-related disorders (Tables 4 and 5). However, H1 developed superficial scald (Table 5).

Table 3. Harvest maturity of Bartlett pears harvested on 3 successive dates surrounding commercial maturity (H2) from IFP block, OSU-MCAREC. No internal or exogenous ethylene was detected for any harvest.

Harvest	Weight per fruit (g) ¹	I _{AD} (DA meter) ²	hue ³	Firmness (lbf)	Brix (°Bx)	TA
H1	225 C	2.05 C	115.9 A	21.2 A	11.54 B	0.43 ns
H2	240 B	2.00 B	115.2 B	19.5 B	11.91 A	0.44 ns
H3	291 A	1.92 A	114.9 B	18.5 C	11.56 B	0.42 ns
Pr<F	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	0.2555

1. Values in a column followed by different letters are statistically different at $p < 0.05$.
2. DA meter; an indicator of green color (lower values indicate less green); for more information, see Hanrahan and Roder in References.
3. Hue, measured by colorimeter; lower values indicate less green color.

Table 4. Advanced harvest maturity is linked with more rapid ripening and quality loss before ULO storage. Effects of harvest timing on post-storage quality for ‘Bartlett’. Approximately 5 months after harvest (January 2025), immediately upon removal from cold, earlier harvested fruit were had higher internal ethylene, lower internal carbon dioxide production, and higher I_{AD} and firmness than later harvest fruit. Overall results indicated physiologically less senescence for earlier harvested fruit. Controlled atmosphere (CA) conditions were 1.5% O₂, ~0% CO₂.

harvest	ripening (days)	internal ethylene concentration (ppm)	internal CO ₂ (ppm)	I _{AD}	firmness (lbf)
early	0	42.83 ns	5631.56 b	1.87 a	18.53 a
early	4	.	.	0.69 e	3.05 e
middle	0	55.84 ns	4697.09 b	1.61 c	17.87 c
middle	4	.	.	0.55 f	3.70 e
late	0	78.03 ns	7138.62 a	1.70 b	15.79 b
late	4	.	.	0.61 e	4.47 d

Objective 3. Evaluate the influence of modified atmosphere packaging (MAP) on fruit quality post long-term CA storage.

Packed Bartlett pears were obtained from a production facility in the Hood River area after approximately 5 months of CA storage. Pears were repacked into boxes lined with either perforated polyethylene (control) or modified atmosphere (MAP) liners (LifeSpan, Amcor Inc., Zurich, Switzerland) and stored at either 30 °F or 45 °F (the latter temperature simulating an extended broken cold chain) for up to 1 month. Comparisons reflect only quality differences resulting from the interaction of the influence of post-storage temperature and box liner material as information on the prior CA storage environment is incomplete. Relative fruit quality is presented in Table 6.

After 2 weeks at 45 °F, fruit that were not in a MAP bag had deteriorated beyond edibility. There was no difference in quality of those stored at 30 F for 6 weeks. All pears ripened fully once moved into 70 F for

5 days. The present results indicate the utility of MAP in cold chain breaks, conditions warmer than ideal holding temperatures (Tables 6 and 7).

Table 5. Disorder incidence and severity according to harvest timing. Earlier harvested ‘Bartlett’ fruit had higher incidence of superficial scald; internal browning incidence was not statistically different according to harvest timing. Storage atmosphere interaction with temperature treatment was not statistically significant for either disorder (data not shown). No senescent scald was observed. A fruit or two with unusual retention of green lenticels was also observed for the earliest harvest. n = 622 total fruit.

harvest	superficial scald incidence (%)	superficial scald severity (% peel area affected)	senescent core browning incidence (%)	senescent core browning severity (0-3 scale)
early	11.1	3.8	0.5	1
middle	0.5	1.0	0	0
late	0	0	1.4	3
Chi-square test statistic	<0.0001	-	0.1763	-
F-statistic	-	<0.0001		<0.0001

MAP bag atmospheres over the course of the experiment are indicated in Table 8. Research by Wang and Sugar (2013) indicated that experimental MAP materials produced low oxygen conditions and relatively higher CO₂ (2.2% O₂ and 5.7% CO₂) corresponded with greater incidence of internal browning after 3-4 months. Conversely, commercial MAP materials with relatively higher oxygen (12.3% O₂ and 5.7% CO₂) allowed for fruit to be stored 3-4 months without issue. In the present study, at 45 °F, resulting CO₂:O₂ ratios far exceed recommendations established by Wang and Sugar (2013), but in short-term storage (<6 weeks), MAP at 45 °F (simulation of transport cold chain break) still led to superior quality outcomes relative to fruit in perforated polyethylene bags. The decrease of CO₂ and increase of O₂ for Packinghouse 2 at 45 °F correspond to fruit senescence, that is, dying fruit. It is important to note that following the termination of the experiment, CO₂ levels continued to increase and O₂ levels continued to decrease. Research in 2025 will extend the duration of fruit stored in MAP post-packing at 30 °F to address this outcome.

Ethylene levels built up in MAP at 45 °F relative to MAP at 30 °F (not shown). Additionally, MAP appeared to initially suppress ethylene production relative to beginning levels at 30 °F. The apparent retention of ethylene in MAP bags warrants further study. This aspect of post-packing MAP will be expanded in 2025. Wang and Sugar (2013) did not report ethylene levels in MAP. The effect of MAP on *Mucor rot* (*Mucor pyriformis*) was also evaluated, indicating suppression of *M. pyriformis* growth rate.

MAP liners allow more accumulation of 1-MCP

The purpose of this experiment was to evaluate the efficacy of 1-methylcyclopropene (1-MCP) sachets for extending late storage season (5 months) of Bartlett fruit following CA storage. Packed pears obtained from a Hood River area packing facility after 5 months storage were repackaged in boxes lined with LifeSpan MAP liners or conventional perforated plastic liners, and treated with 1-MCP sachets. Treatments included: 1) control, no sachets; 2) MAP bags (LifeSpan™), 3) three 1-MCP sachets (0.014%, SmartFresh Inbox, Agrofresh), 4) six 1-MCP sachets, 5) MAP plus three 1-MCP sachets, and 6) MAP plus six 1-MCP sachets.

Table 6. Fruit quality in response to MAP, temperature, and post-repacking (re-packing into MAP) duration. Fruit stored at 45 °F in perforated polyethylene bags (control) were discarded at 2 wk post-packing prior to ripening and 4 wk post-packing due to deterioration. Average pre-experiment I_{AD} was 1.79, firmness 8.2 lbf.

	Bag type ¹	Temp. (°F)	Weeks post-re-packin g	I _{AD} (DA meter ²)		Flesh firmness (lbf)		Senescent scald (peel defect) ³		Senescent core breakdown (flesh defect) ⁴	
Unripened (day 0 post-experimental storages)	control	30	2	1.68	ab	11.5	a	0.61	cd	0	b
			4	1.64	ab	7.8	cd	0.86	abc	0	b
			6	1.60	bc	7.6	cd	0.30	d	0	b
	MAP	30	2	1.76	a	8.3	bc	0.97	ab	0	b
			4	1.71	ab	7.4	de	0.77	bc	0.03	b
			6	1.60	bc	7.5	d	0.66	bc	0.03	b
	control	45	2	1.03	d	4.3	f	1.13	a	0	b
			4	--	--	--	--	--	--	--	--
			6	1.63	bc	9.0	b	0.77	bc	0	b
	MAP	45	2	1.30	d	5.1	f	1.11	a	0.42	a
			4								
	Pr<F (Overall model, postharvest handling) ^{5,6}				<0.0001		<0.0001		<0.0001		<0.0001
Ripened (day 5 post-experimental storage)	control	30	2	0.63	ns	2.0	c	1.25	ab	0.03	d
			4	0.57	ns	2.1	bc	1.19	bc	0.53	c
			6	0.53	ns	2.2	bc	1.11	bc	0.58	c
	MAP	30	2	0.56	ns	2.3	b	0.91	c	0.20	cd
			4	0.51	ns	2.8	a	1.11	bc	0.44	cd
			6	0.50	ns	2.6	a	1.13	bc	0.31	cd
	control	45	2	--	--	--	--	--	--	--	--
			4	--	--	--	--	--	--	--	--
			6	--	--	--	--	--	--	--	--
	MAP	45	2	0.54	ns	2.1	bc	1.19	bc	1.19	b
			4	0.51	ns	2.2	bc	1.50	a	3.20	a
	Pr<F (Overall model Postharvest handling) ^{5,6}				0.4599		<0.0001		0.0175		<0.0001

1. Control = perforated polyethylene, MAP = LifeSpan brand.
2. DA meter; an indicator of green color (lower values indicate less green); for more information, see Hanrahan and Roder in References.
3. Senescent scald peel defect, surface area affected: 0 = none, 1 = >0-10%, 2 = 11-50%, 3 = 50%-100%
4. Senescent core breakdown flesh defect: 0 = none, 1 = >0-10%, 2 = 10%-50%, 3 = 51-75%, 4 = 76-100% when cutting across the core horizontally.
5. Experimental factors were combined into a single term “handling” for a one-way ANOVA. Values in a column followed by different letters are statistically different at $p < 0.05$. Day 5 of ripening was analyzed separately from day 0.

Pears were stored in air at 32 °F. Ethylene, carbon dioxide, and 1-MCP (3 or 6 sachets, low or high rate, respectively) were estimated 2 h following initial treatment and, then, weekly for 4 weeks via septa affixed to the liners. The MAP bag improved 1-MCP accumulation (Table 8) but had no consistent impact on fruit quality (Table 9). MAP bags lessened quality loss regardless of 1-MCP addition (Table 9). As pears selected for this experiment had already undergone an unknown degree of ripening during commercial storage in higher-than-ULO conditions, it is nearly impossible to assess the degree to which they would be receptive to ripening inhibition by 1-MCP, even at a very high rate. Both apple (DeEll et

al.; Poirier et al., 2021) and pear ripeness (Rudell et al., current d'Anjou project) can be reduced during the post-storage cold chain using 1-MCP treatment ripening or processes leading to ripening are adequately checked by the CA storage environment. This means the lower the O₂%, the more ripening is impacted by post-storage 1-MCP. Pears used for this activity in the current season will be assessed for relative post-CA storage ripeness or stored at atmospheres <1% O₂ in experimental chambers prior to 1-MCP fumigation or sachet application.

Table 7. Summary of temperature and storage duration as impacted by MAP liners. In the present study (6 weeks in MAP liners in air following approximately 5 months CA storage), MAP was most useful for retaining fruit quality when there was a break in the cold chain.

Quality attribute				
	Color (DA meter)	Flesh firmness	Senescent scald	Senescent core breakdown
Summary	Warmer temperatures without MAP leads to loss of green in cold chain	Warmer temperatures without MAP increases firmness loss	Higher temperatures lead to higher incidence of senescent scald; effects of MAP on senescent scald unclear	Higher temperatures lead to higher incidence of senescent core breakdown; no discernable effect of MAP on senescent core breakdown

Table 8. Three hours after application, 1-MCP from sachets (0.014% 1-MCP per sachet) in boxes lined with MAP liners. Sachets were wetted prior to application and added at the low (3 count) or high (6 count) label rate per box. 1-MCP was not detectable in any bags after the second week of the experiment.

1-MCP sachets (#)	bag	storage temperature	ethylene (ppm)	CO ₂ (ppm)	MCP (ppm)
0	MAP	32 °F	49.4	3165.2	0.0000
0	perf. poly.	32 °F	7.2	6976.4	0.0000
3	MAP	32 °F	30.9	4091.1	1.3260
3	perf. poly.	32 °F	17.7	3950.2	0.4110
6	MAP	32 °F	38.2	5278.4	4.4493
6	perf. poly.	32 °F	5.0	3964.8	0.4411

No statistics performed.

Table 10. MAP liners suppressed Bartlett pear ripening and preserved fruit quality after 5 months CA storage and 4 weeks air storage (32 °F) while 1-MCP sachets (0.014%) had no effect at either the low (3 count) or high (6 count) label rate. Senescent scald incidence was minimal (data not shown). 1-MCP treatment did not impact internal browning incidence while map reduced symptom incidence and severity compared with perforated polyethylene bags (data not shown), and for fruit affected by internal browning.

1-MCP sachets (#)	bag	ripening (days)	DA	firmness (lbf)	Internal browning severity (0-4)		
0	MAP	0	1.47	ab	15.0 a	.	
0	perf. poly.	0	1.60	a	14.9 a	1.0	
3	MAP	0	1.53	ab	15.1 a	.	
3	perf. poly.	0	1.34	b	12.4 c	.	
6	MAP	0	1.34	b	15.1 a	.	
6	perf. poly.	0	1.35	b	13.7 b	.	
		overall	0.0090		<0.0001		
		MCP	0.0187		0.0860		
		MAP	0.8028		<0.0001		
		MCP*MAP	0.0666		0.0034		
0	MAP	7	0.09	b	3.1 bc	2.7	B
0	perf. poly.	7	0.13	b	2.1 cd	3.8	A
3	MAP	7	0.40	a	5.4 a	2.8	B
3	perf. poly.	7	0.13	b	2.0 d	3.8	A
6	MAP	7	0.06	b	3.3 b	2.8	B
6	perf. poly.	7	0.13	b	2.0 d	3.8	A
		overall	<0.0001		<0.0001	0.002	
		MCP	0.003		7E-04	0.955	
		MAP	0.2407		<0.0001	<0.0001	
		MCP*MAP	0.0031		4E-04	0.971	

Post hoc means separation are according to main effects “MCP” or “MAP” (capital letters) or “MCP*MAP” (lowercase letters).

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

Report Type: Final Project Report

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Cooperators: Dr. DoSu Park; Emmi Klarer

Project Duration: 3 Year

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

Total Project Request for Year 2 Funding: \$ 70,395
Total Project Request for Year 3 Funding: \$ 71,910

Other related/associated funding sources: Awarded

Funding Duration: 2022 - 2024

Amount: \$ 236,147

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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Contract Administrator: Sharon Blanchard

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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.

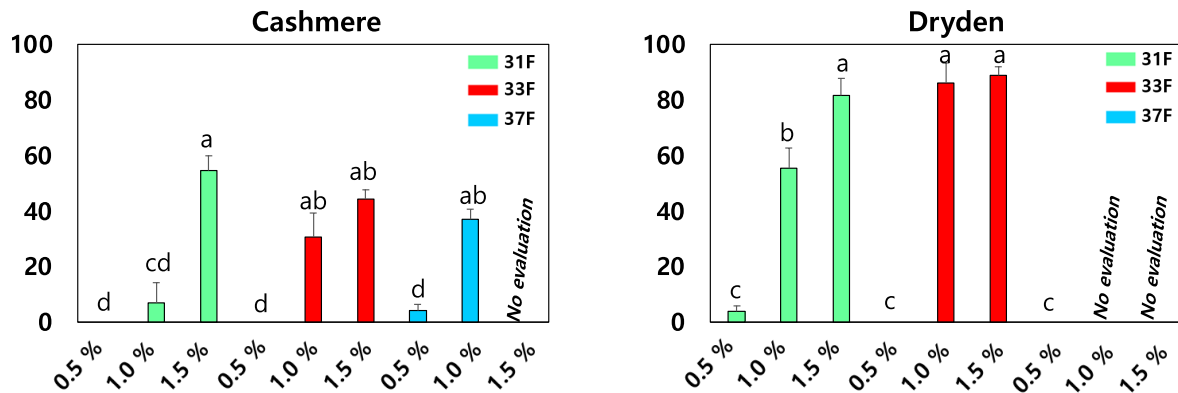


Figure 1. Percent superficial scald incidence in d'Anjou pears from two orchards in year 1 after 8 months of CA storage with a range of O₂ levels and temperature combinations, followed by 4 weeks of storage at 33 °F, and 7 days at 68 °F. Superficial scald was significantly lower on pears stored at 0.5% 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 ($p \leq 0.05$).

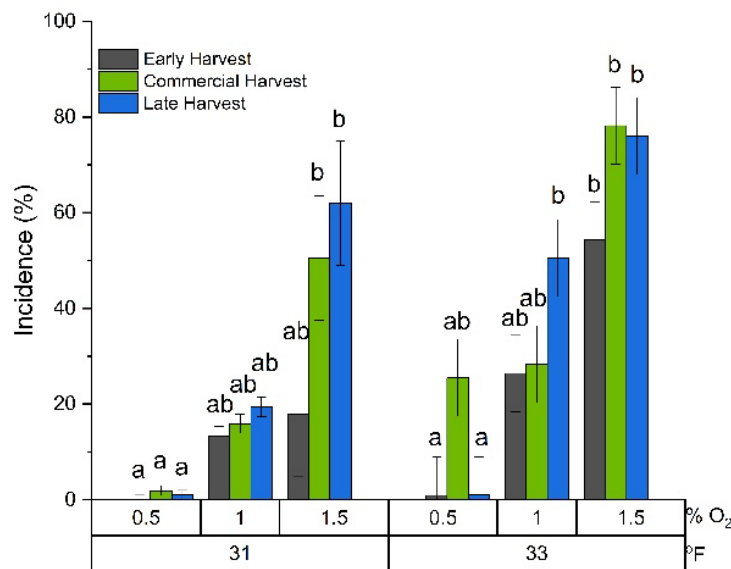


Figure 2. Superficial scald incidence in d'Anjou pears harvested from Cashmere, WA. (A) Pears harvested at different maturities in year 2 and stored in a range of O₂ levels and temperature combinations, followed by 4 weeks of storage at 33 °F, and 7 days at 68 °F. Different lowercase letters indicate 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.

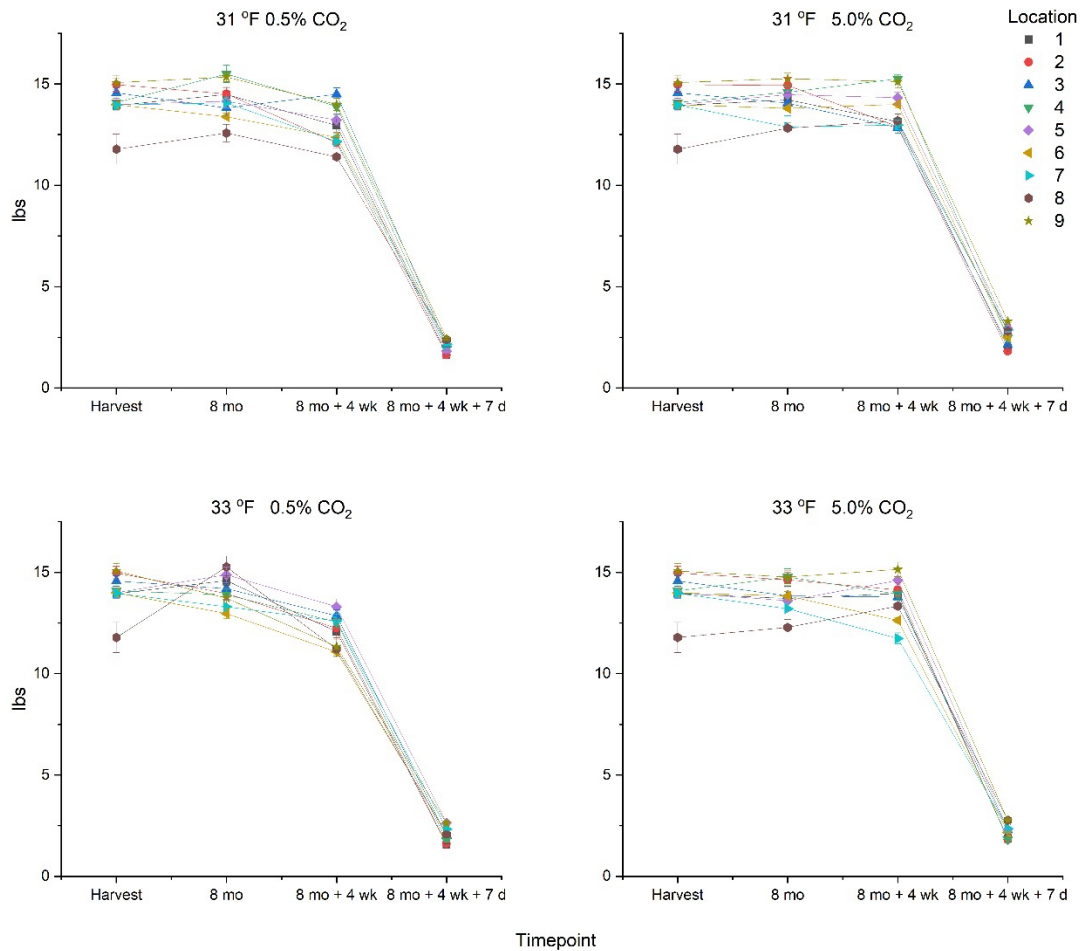


Figure 3. Firmness of d’Anjou pear firmness harvested from 9 different orchards in year 3 between harvest and throughout the simulated cold chain. (Note: x-axis is not to scale.) All pears were stored in ULO (0.5% O₂) and either 0.5 or 5.0% CO₂, and 31 or 33 °F. Pears maintained firmness until transferred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

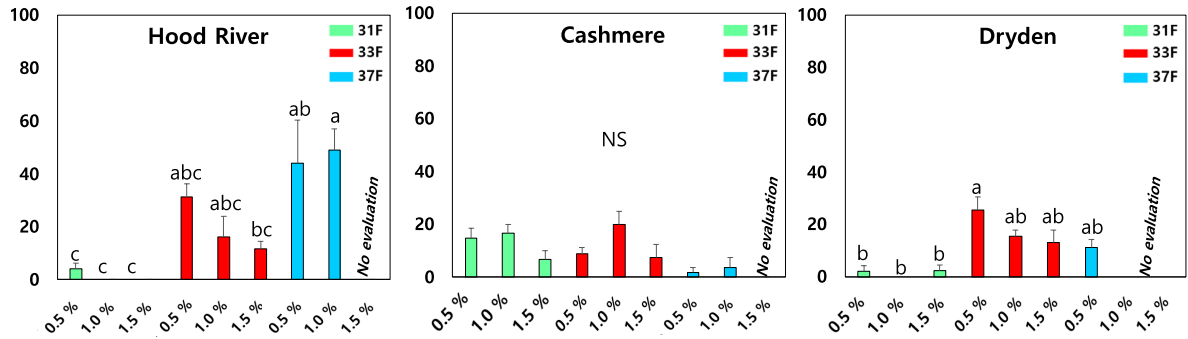


Figure 4. Pithy brown core incidence of d’Anjou pears harvested from 3 orchards following 8 months storage under variable O₂ (0.5% CO₂) and temperature conditions followed by 4 weeks at 33 °F and 7 days at 68 °F. Pithy brown core was reduced by lower temperature or remained the same in pears from 2 orchards. 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.

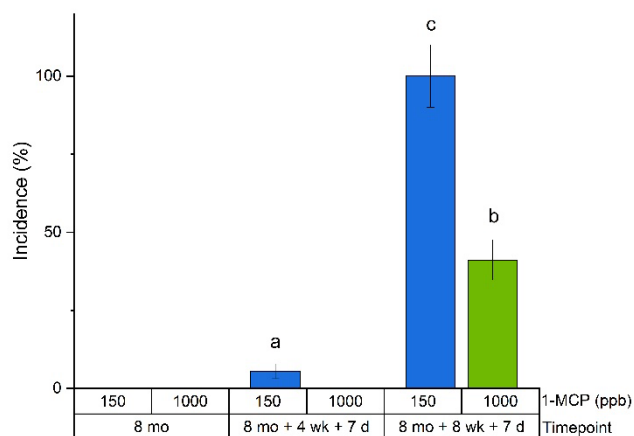


Figure 5. Superficial scald incidence on d'Anjou pears following 8 months of ULO CA storage followed by treatment using either 150 ppb or 1000 ppb 1-MCP, then 4 weeks or 8 weeks at 33 °F and 7 days at 68 °F. Different lowercase letters indicate significant groups among treatments according to a z-test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

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

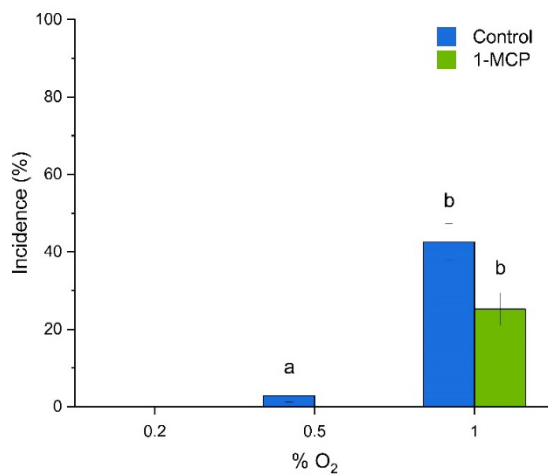


Figure 6 Superficial scald incidence of d’Anjou pears in year 3 following 8 months of CA storage with variable O₂ levels followed by treatment with 1000 ppb 1-MCP, then 4 weeks or 8 weeks at 33 °F and 7 days at 68 °F to simulate cold storage, distribution, and retail shelf time. Different lowercase letters 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.

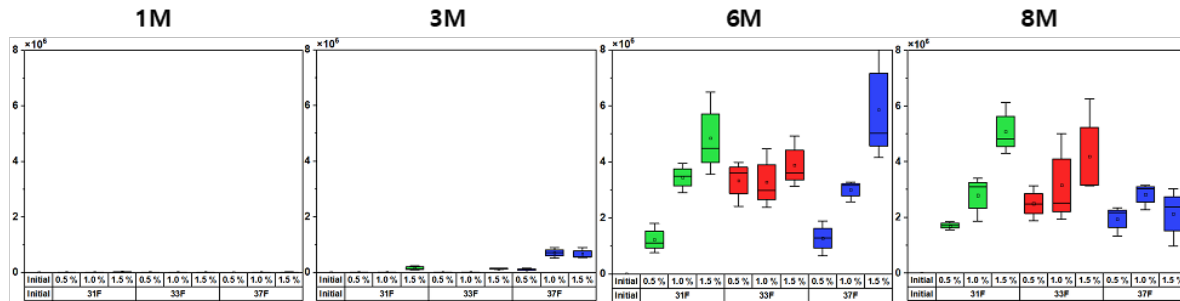


Figure 7. Accumulation of conjugated trienol (CTOL) in peel of d’Anjou pears harvested from Cashmere, WA and stored in 0.5% CO₂ plus 0.5%, 1%, or 1.5% O₂ at 31, 33, or 37 °F. CTOL accumulation is associated with the environmental conditions that cause superficial scald. Results here reflect the final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

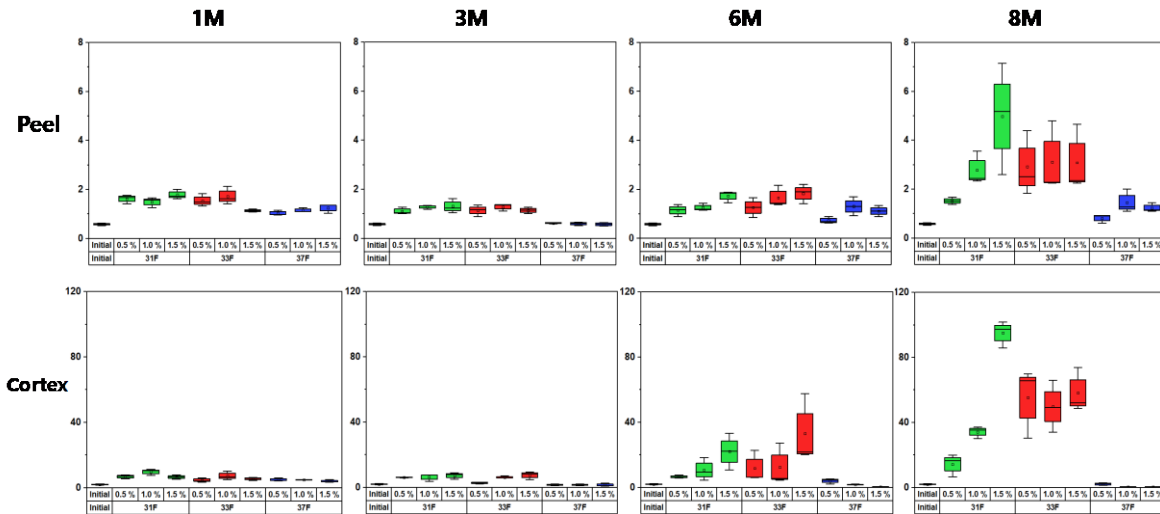


Figure 8. Changes of the ASG to SE ratio in peel and cortex of d'Anjou pears harvested from Cashmere, WA and stored in 0.5% CO₂ plus 0.5%, 1%, or 1.5% O₂ at 31, 33, or 37 °F. Elevated ASG/SE in peel is associated with superficial scald in apple and, in cortex, with soggy breakdown and CO₂-related browning 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.

Project Title: Germplasm evaluation for fruit quality and post-harvest traits

Report Type: Final Project Report

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Cooperators: None

Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$ 33,000

Total Project Request for Year 2 Funding: \$ 12,000

Total Project Request for Year 3 Funding: \$ 10,000

Other related/associated funding sources: Requested

Funding Duration: 2026 - 2030

Amount: \$ 4,000,000+

Agency Name: USDA SCRI

Notes: Title: Integrating multidisciplinary and translational approaches to manage postharvest rots on apples and pears in major U.S. pome fruit growing regions. All three PIs are listed as co-PIs on this project.

Other related/associated funding sources: Requested

Funding Duration: 2026 - 2030

Amount: \$640,000

Agency Name: USDA NIFA

Notes: Title: Leveraging diverse germplasm resources to develop breeding tools for resistance to bitter rot in pome fruit. PI Gottschalk is lead PI for this proposal and co-PI Collum is listed as co-PI.

WTFRC Collaborative Costs:

Item	2022	2023	2024
Salaries			
Benefits			
Wages			
Benefits			
RCA Room Rental			
Shipping	\$6,000.00	\$6,000.00	\$6,000.00
Supplies	\$4,000.00	\$4,000.00	\$2,000.00
Travel	\$3,000.00	\$2,000.00	\$2,000.00
Plot Fees			
Miscellaneous			
Equipment	\$20,000.00		
Total	\$33,000.00	\$12,000.00	\$10,000.00

Footnotes:

Budget 1

Primary PI: Dr. Christopher Gottschalk

Organization Name: USDA ARS

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Benefits			
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies	\$1,700.00	\$3,400.00	\$1,700.00
Travel	\$3,000.00	\$2,000.00	\$2,000.00
Plot Fees			
Miscellaneous			
Equipment	\$18,500.00		
Total	\$23,200.00	\$5,400.00	\$3,700.00

Footnotes:

If project duration is only 1 year, delete Year 2 and Year 3 columns.

Budget 2**Co PI 2: Dr. Lauri Reinhold****Organization Name: USDA ARS****Contract Administrator: Stefani Morgan****Telephone: (541) 738-4023****Contract administrator email address: stefani.morgan@usda.gov****Station Manager/Supervisor: Carolyn Scagel****Station manager/supervisor email address: carolyn.scagel@usda.gov**

Item	2022	2023	2024
Salaries			
Benefits			
Wages			
Benefits			
RCA Room Rental			
Shipping	\$6,000.00	\$6,000.00	\$6,000.00
Supplies	\$2,300.00	\$600.00	\$300.00
Travel			
Plot Fees			
Miscellaneous			
Equipment	\$1,500.00		
Total	\$9,800.00	\$6,600.00	\$6,300.00

Footnotes:

Objectives: Our project has four objectives that complementarily address the evaluation of pear germplasm for post-harvest traits. The first objective is to evaluate the USDA Pear Collection for optimal harvest and storage time for 50 high-value genotypes. We proposed using two germplasm sources to acquire 50 genotypes: 1) USDA Pear Collection at the USDA ARS National Clonal Germplasm Repository (NCGR) in Corvallis, OR, which contains nearly 2,300 unique pear cultivars, breeding lines, and hybrids that represent 36 species and 2) the USDA ARS Appalachian Fruit Research Station (AFRS) breeding program in Kearneysville, WV. The aims are to evaluate the lines for harvest dates, storage requirements, and the presence/absence of post-harvest diseases. We are approaching the disease evaluations in a two-step process. First, evaluate the fruit for natural infections and the classification of pathogens present. Second, conduct resistance testing by inoculating the genotypes found to be free of natural infection for resistance to the identified pathogens. The second objective is to characterize the 50 high-value genotypes for fruit quality, attributes including total soluble solids, acidity, polyphenolic content, texture, peel and flesh color, and overall grade. This objective aims to characterize fruit quality traits using two approaches, destructive and non-destructive, correlate their measures, and develop models used to predict the destructive trait measurements using the non-destructive equipment in the future. The third objective is to challenge the 50 high-value genotypes in simulated supply-chain stress to document resistance to bruising, scuffing, and puncturing. This objective aims to identify germplasm that can withstand the intense forces that are exerted on the fruit during the supply-chain process. However, we have found that fruit received from NCGR pear collection undergoes shipping stress and upon receipt can exhibit real-life damage. We have deviated from our initial objective here to take qualitative measures from the NCGR fruit since it has already been subjected to the planned stresses. Genotypes that exhibit

damage are noted and the damage type is described. The fourth objective is to document and distribute findings through publications and presentations regarding the resistance of the 50 high-value genotypes to storage disorders and diseases. The aim here is to provide communication with the stakeholders and provide any products developed from the analyzes as impactful tools for evaluation of post-harvest traits in pear.

Significant Findings

Objective 1:

- Evaluated over 100 unique genotypes for harvest date and conditioning requirement.
- Evaluated 100 genotypes for susceptibility to *Penicillium expansum* and 97 genotypes for susceptibility to *Colletotrichum fioriniae* (46 from NCGR and 54 from AFRS).
- Identified six additional genotypes that were significantly less susceptible to *P. expansum* and *C. fioriniae* compared to ‘Bartlett’ and ‘Gem’ in 2025.

Objective 2:

- Identified numerous genotypes associated with large fruit size, high sugar content, and high acidity.
- Identified the range of tannic acid in *Pyrus communis*, including content levels associated with standard cultivars.

Objective 3:

- Conducted a first of its kind phenotyping assay to determine supply chain resilience, which identified two potential sources of resiliency.

Methods

Objective 1: We identified high-value germplasm from historical texts, the USDA GRIN database, and recommendations from germplasm curators and previous breeders. The terms that were used as queries in the literature search for desirable genotypes included disease-resistance (fire blight, *Monolinia*, and post-harvest pathogens), ships well, excellent flavor, keeps well, fruit quality, acidic, phenolic (non-perry), early ripening, late-ripening, and tree-ripe. Following bloom and prior to the fruit ripening period, crop load was estimated from each tree to determine if the minimal fruit number need for all analyses was available. For harvest timing, our initial approach was to select five randomly selected fruit from each tree were collected weekly. Each fruit was cataloged for color development and underwent firmness testing using a penetrometer with a measurement taken from the sun-exposed and shaded side of the fruit following removal of the peel. A genotype will be determined as harvest-ready when firmness decreases to an average of 20 lbf, and color development has reached its peak. We have found that the simple approach of lifting the pear(s) on a branch from the bottom of the fruit, with a minimal force that resulted in release, the pear was determined as harvest ripe. Several of the AFRS breeding lines correlated with known harvest dates using this approach as opposed to decreases in firmness. Moreover, during the first year of harvest date phenotyping, we found many of the varieties when picked at 20 lbf did not ripen in storage to a sufficient lower firmness level (3 lbf). This result suggests that we were picking fruit too immature. We have modified our harvesting approach to using this more simplistic ease-of-release from the branch to indicate harvest timing. Potentially, this result is due to the hybrid (*Pyrus* spp.) origins of many of the breeding lines at AFRS. We have applied this approach to the NCGR sourced fruit as well which were collected and phenotyped during the 2023 and 2024 seasons.

Each genotype then had 75 fruits, or the maximum available, harvested and packed into 40 lbs fruit boxes and stored at USDA AFRS in a new cold storage unit. For the NCGR fruit, harvested pears were wrapped in a Styrofoam fruit wrapper and placed into trays and packaged into boxes for shipping. Overall, this approach maintained the integrity of many of the shipped genotypes. However, some genotypes were found to still be susceptible to the shipping forces (bruising, scuffing, and punctures) and were damage upon receipt even though significantly protected during the shipping

process. The boxes of fruit were kept in cold storage at 30°F and 90-98% relative humidity. At ten days to biweekly intervals, starting at two weeks in storage to 12 weeks or until ripe, three randomly selected fruit will be taken out of storage and rested at room temperature for 24 - 48 hours. Following the acclimation period, the selected fruit was tested for firmness using a penetrometer. The genotypes were considered ripe when average firmness reaches 3 lbf or less.

A total of 100 pear genotypes (46 from NCGR and 54 from AFRS) were directly challenged with *Penicillium expansum* or *Colletotrichum fioriniae* using a wound inoculation method. Depending on fruit availability ten or twenty fruits from each genotype were inoculated with each pathogen. Fruits were harvested at maturity and inoculated within a week of harvest. On the day of inoculation, fruits were removed from cold storage and allowed to acclimate to room temperature. All fruits were surface sterilized with 70% ethanol and allowed to dry in a laminar flow hood. For *P. expansum* experiments, fruit was wounded with a 3 mm x 3 mm wounding tool and the plug was removed. A conidial suspension was prepared from a 7-day culture of *P. expansum* isolate MD-8 by flooding the plate with sterile distilled water plus Tween-20 and the concentration was adjusted with a hemacytometer to 1×10^4 conidia/mL. 25 μ l drops of the suspension were placed in the wounds with a repeating syringe. For *C. fioriniae* experiments, fruit was wounded with a 4 mm cork borer and the plug was removed. Corresponding plugs were punched from a 7-day culture of *C. fioriniae* isolate WV-223 with the same 4 mm cork borer. *C. fioriniae* plugs were placed mycelium side down into the fruit wounds. For all experiments, inoculated fruits were stored in covered fruit bins at room temperature and lesion diameters were measured at 3-, 5-, and 7-days post inoculation.

Objective 2: We originally proposed using twelve randomly selected pears from each genotype, that are identified as at an optimal eating quality following storage, to be used to evaluate fruit quality traits. However, limited crop loads, higher soft scald incidence, an outbreak of *Fabraea* leaf spot at AFRS, and longer cold condition sampling time points than anticipated required the decrease of the number of replicates to five for this objective. The five fruits first underwent size (length, diameter, and weight) and shape (qualitative) measures. Following non-destructive measurements, all five of the replicate fruit per genotype were analyzed using Near-infrared (NIR) Produce Quality Meter (Felix Instruments). After NIR measurement, each replicate pear was processed to extract juice using a Good Nature M-1 Fruit Grinder and Press. The extracted juice was frozen and underwent measurements for TSS (ATAGO PAL-1), TA and pH (Orion Star T910 Autotitrator), and total polyphenolic content (Folin-Cointreau; absorbance using a spectrometer) using industry-standard measurement methods during the winter months. The data obtained from the NIR meter and industry-standard methods will be inputted into Felix Instrument's model-building software to develop and validate models for the NIR meter for future use. Our initial plan was to use the NIR meter as the sole instrument used to determine all fruit quality metrics except for a juice extraction to determine polyphenolic content in years two and three. However, due to limited availability of fruit from each genotype consistent between years we continued to perform the destructive phenotyping. By collecting more of the ground truth measurements through destructive sampling will only increase our power in training accurate and predictive models using the NIR meter. Due to the limited replicate fruit, we were unable to conduct a sensory evaluation using a trained three-person panel consisting of staff at AFRS.

Objective 3: We will evaluate each genotype for resilience to stress associated with the supply chain including bruising, puncturing, and degradation severity estimation. This objective began during the 2024 season due to the limited fruit available during the 2022 and 2023 seasons and the need to identify the cold conditioning requirements for each genotype across two consecutive years to predict the timing more accurately for evaluations. Additionally, we have found the fruit shipped from NCGR is already subject to real-world shipping stress. As a result, we are modifying this objective to quantitatively document damage to fruit received from NCGR. As for fruit obtained from AFRS, when a genotype has acquired one or two year of storage data, it will be selected for evaluation when excess

fruit is available. We were able to repair and utilize a robot arm to simulate container loading and unloading which would cause bruising along with puncture wounds. The robotic stress was applied by having the robot's arm traverse a horizontal space at speed setting that mimics truck movement on the roadway and a drop treatment that covers a distance of 600 mm in < 1 sec. The robotic-associated testing occurred at AFRS under the guidance of Dr. Amy Tabb who has performed similar simulations. To evaluate the fruit under these two conditions, eight replicated fruits were randomly selected for each genotype. Fruit was then placed into a cardboard box with a trimmed down cardboard fruit insert on both the top and bottom sides (clam shell). On top of the upper fruit insert, a sheet of one cm diameter bubble wrap was used to serve as an additional cushion. Fruit was then enclosed in the box with the packaging and placed onto the robot arm. The fruit was then subjected to 30 mins of the shaking and five simulated drops in succession. Following the stress, the fruit was rested for four to five days at room temperature and then evaluated for presence/absence of bruising, puncture, and degradation severity. The same quantitative measures were taken from the NCGR shipped fruit.

Objective 4: The results gained from Objectives 1-3 will be presented and distributed to the research community and stakeholders.

Results and Discussion

Objective 1: The identification of 50 high-value varieties from historic literature was successful. We additionally, were able to properly re-identify 60+ genotypes in the historic AFRS germplasm. Unfortunately, in year one, a minor frost in the spring of 2022 and biennial bearing habits extremely limited the fruit available for the NCGR. In 2022, we obtained harvest dates for 43 genotypes all sourced from AFRS. In 2023, we obtained harvest dates for 69 genotypes. Of those 69, 29 were collected from the NCGR and remaining 40 from AFRS. In 2024, we obtained harvest dates for 113 genotypes. Of those 113, 49 were collected from the NCGR and remaining 64 from AFRS. In 2025, we obtained harvest dates for 57 genotypes. Of those 57, 33 were collected from the NCGR and remaining 24 from AFRS. Unfortunately, a spring frost at AFRS and the lapse in government funding during harvest limited the total varieties that we were able to harvest. In total, we evaluated a combined 130 unique genotypes across the three years of this project. 22 genotypes were collected for a single season, and 98 genotypes were collected over two or three seasons. This result represents a 260% increase in the genotypes evaluated over what was proposed.

The measurement and documentation of condition requirement was successful in each year of the project. However, the total number of genotypes with conditioning requirement evaluations done was less than what we obtained for harvest date. This limitation stems from complexities to ripening fruit. For example, some genotypes were unable to meet the target firmness to be called "conditioned" because they developed storage disorders such as scald and decomposition. In 2022, we documented conditioning requirements for 32 genotypes. In 2023, we documented conditioning requirements for 71 genotypes. In 2024, we documented conditioning requirements for 94 genotypes. In 2025, we documented conditioning requirements for 49 genotypes. Throughout the four years of this project, 37 genotypes have documented conditioning requirements based on a single season observation and 77 genotypes have documentation for two or three seasons. In total, we documented a combined 114 unique genotypes across the three years of this project. We were able to document condition requirement for 88% for the genotypes we harvested.

For the past three seasons, we have documented harvest date and cold conditioning requirements for >100 unique genotypes. We have documented a strong peak in harvesting dates for pears between 203 and 297 days into the calendar year (July 22nd – October 24th) (**Fig. 1A**). The mean harvest date for pears evaluated in this study was on the 241th day of the year (August 29th). However, a few varieties were found to be harvesting after October 2nd and represent extremely late ripening genotypes. The cold conditioning requirements for the pears evaluated in this study ranged from as low as 8 days to a much as 119 days post harvesting (**Fig. 1B**). A few varieties, namely pink-fleshed

pears, were found to be ripe upon harvesting such as 'Summer Blood Birne'. Two peaks in conditioning requirement were observed between 25 and 75 days. The mean requirement for conditioning was ~46 days. Although weakly correlated (Kendall's $\tau = 0.15$), harvest date was significantly associated with the cold conditioning requirement (**Fig. 1C**). We found many genotypes that were exceptions to this trend - harvested relatively early yet required extensive condition time to reach desirable firmness. These genotypes include varieties such as 'Talgarskaya Krasavitza' and 'Giant Seckel' and breeding lines NJ Rock R27 T65 and US 84909-184. These genotypes could serve the purpose to breed for conventional harvest dates with long conditioning requirements, resulting in longer marketing window for pear. Alternatively, several genotypes were identified as having short conditioning requirements and represent more ideal material for direct-to-market applications and breeding objectives. These genotypes included varieties such as 'Bell', 'Mac', 'Summercrisp', and breeding lines such as NY 10355 and US 84907-078. Furthermore, varieties such as 'Passe Crassane' and Marie Louise' could be used to target late harvest dates but low conditioning requirements. Testing if harvest date and conditioning requirement is predictively inherited needs to be tested.

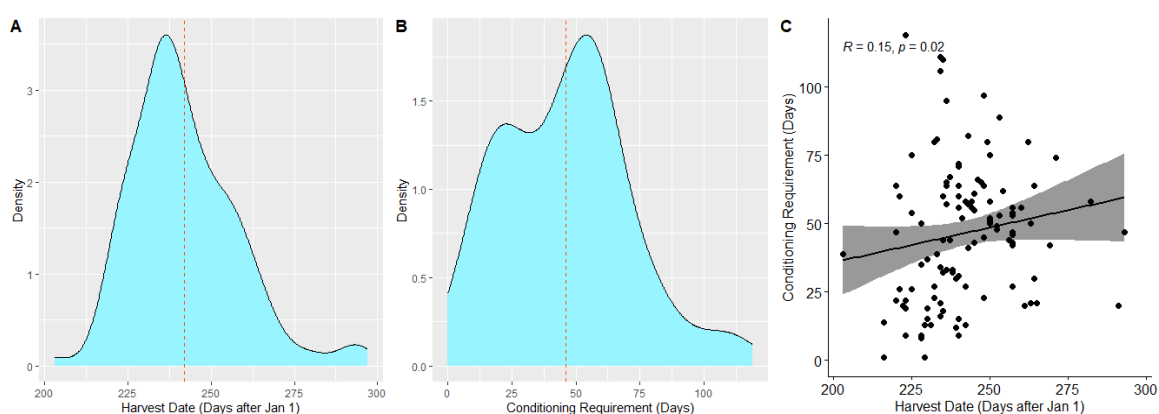


Figure 1. A) Variation in harvest date for pear germplasm. B) Cold conditioning requirements in pear germplasm. C) Correlation plot between harvest and cold conditioning requirement. Red dashed lines indicate the mean. Correlation significance test conducted using Kendall's τ test.

A total of 100 unique genotypes (46 from NCGR and 54 from AFRS) were challenged with *P. expansum* and 97 genotypes (43 from NCGR and 54 from AFRS) were challenged with *C. fioriniae*. 'Gem' and 'Bartlett' were included as controls that are highly susceptible to both *P. expansum* and *C. fioriniae*. 58 genotypes were challenged during a single season, 40 genotypes were challenged in two seasons, and 2 genotypes ('Gem' and 'Shenandoah') were challenged in three seasons.

The mean decay lesion diameter after 7 days ranged from 10.70 mm to 39.35 mm for *P. expansum* and 6.58 mm to 30.11 mm for *C. fioriniae* (**Fig. 2**). For pears harvested at AFRS there was not a significant difference between mean decay lesions based on year. For pears harvested at NCGR, there was a significant increase in mean decay lesion in 2025 compared to 2024 for both pathogens. This highlights the importance of testing genotypes over multiple seasons to account for differences in weather and disease pressure. We found seven genotypes had significantly reduced lesion sizes when challenged with *P. expansum* compared to 'Bartlett' in 2024. These included three from NCGR ('Golden Spice', 'Riehl Best', and 'Napoleon') and four from AFRS (US 71643-047, US 79439-004, US 83825-223, US 99422-202) (**Fig. 3**). All genotypes that were identified as significantly less susceptible to *P. expansum* in 2024 were also significantly less susceptible to *C. fioriniae* except for Napoleon which was not challenged with *C. fioriniae* due to limited fruit. Napoleon has previously been reported to be resistant to the pathogen *Monilinia*. Two of the identified genotypes (US 83825-223 and US 79439-004) were also tested the previous year. In 2023, US 83825-223 was also significantly less susceptible to *P. expansum* and *C. fioriniae* compared to 'Gem' and 'Bartlett', while

79439-004 was significantly less susceptible to *C. fioriniae* but not *P. expansum*. In 2025, six additional genotypes that were significantly less susceptible to *P. expansum* and *C. fioriniae* were identified. They included one from NCGR ('Duchesse d'Angouleme') and five from AFRS (US 83825-020, US 79417-021, US 78302-018, NJ Rock R21 T227, and NJ 487601193). Due to low fruit ability the only genotype identified in 2024 that was retested in 2025 was 'Riehl Best', which was again significantly less susceptible than 'Bartlett' for both pathogens.

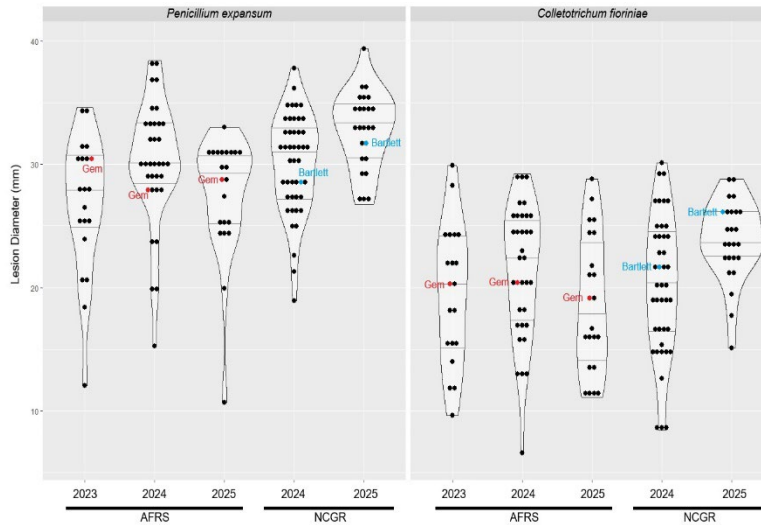


Figure 2. Variation in mean decay lesion diameter in pear germplasm 7 days after inoculation with *Penicillium expansum* or *Colletotrichum fioriniae*. The mean lesion diameter of each pear genotype tested in 2023, 2024, and 2025 is represented by a dot. Lines indicate the lower quartile, median, and upper quartile. Control genotypes 'Gem' and 'Bartlett' are indicated by red and blue dots respectively.

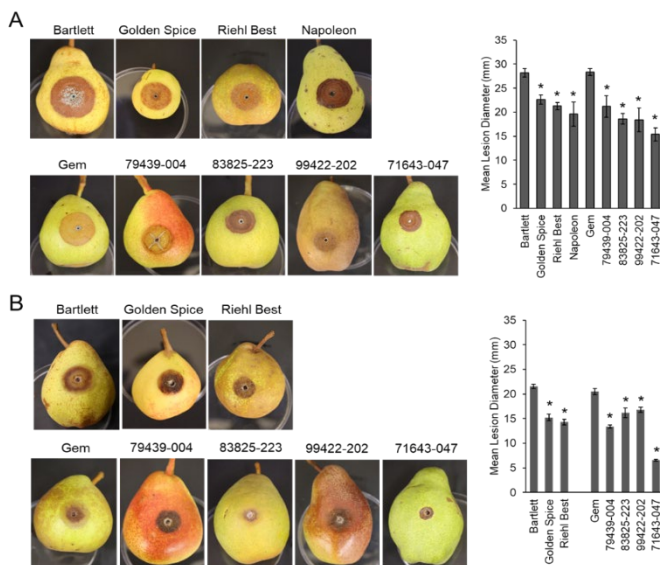


Figure 3. Wound inoculation of pear genotypes with *Penicillium expansum* (A) or *Colletotrichum fioriniae* (B). A representative image of lesion development 7 days post inoculation is shown for selected pear genotypes inoculated in 2024. Bars represent the mean lesion diameter (mm) ± standard error. A * indicates a significant difference of $p < 0.05$ compared to Bartlett using a one-way ANOVA followed by post-hoc Dunnnett's test.

We have analyzed 117 unique genotypes of pear for fruit quality traits from 2022-2024, with the 2025 data to be processed by early spring 2026. These traits are represented as replicated measurements on a per replicate pear basis for juice yield, total soluble sugar (TSS) content (°Brix), pH, titratable acidity (TA), and total phenolic content (bitterness). For 67 genotypes, we have documented fruit quality across two or three seasons. The remaining 50 genotypes have only a single season representation. Within this germplasm, we found that the average juice yield was ~89 mL/fruit (**Fig. 5A**). The juiciest varieties were found to be breeding lines including US 99415-026 at 171 mL/fruit. For sweetness, we identified several historic varieties that were nearly two-fold higher than the germplasm's average of ~13 Brix (**Fig. 5B**). These high TSS varieties include 'Louise Bonne d'Avranches' (25.98° Brix), 'Urbaniste' (21° Brix), 'Riehl Best' (20.68° Brix), and 'Olivier de Serres' (19.8° Brix). The highest TSS value in the USDA breeding program was US 78302-022 at 14.63° Brix. Titratable Acidity (TA) within the germplasm averaged 3.83 g/L (**Fig. 5D**). However, we identified three breeding lines that were three- to four-fold higher than the average (US

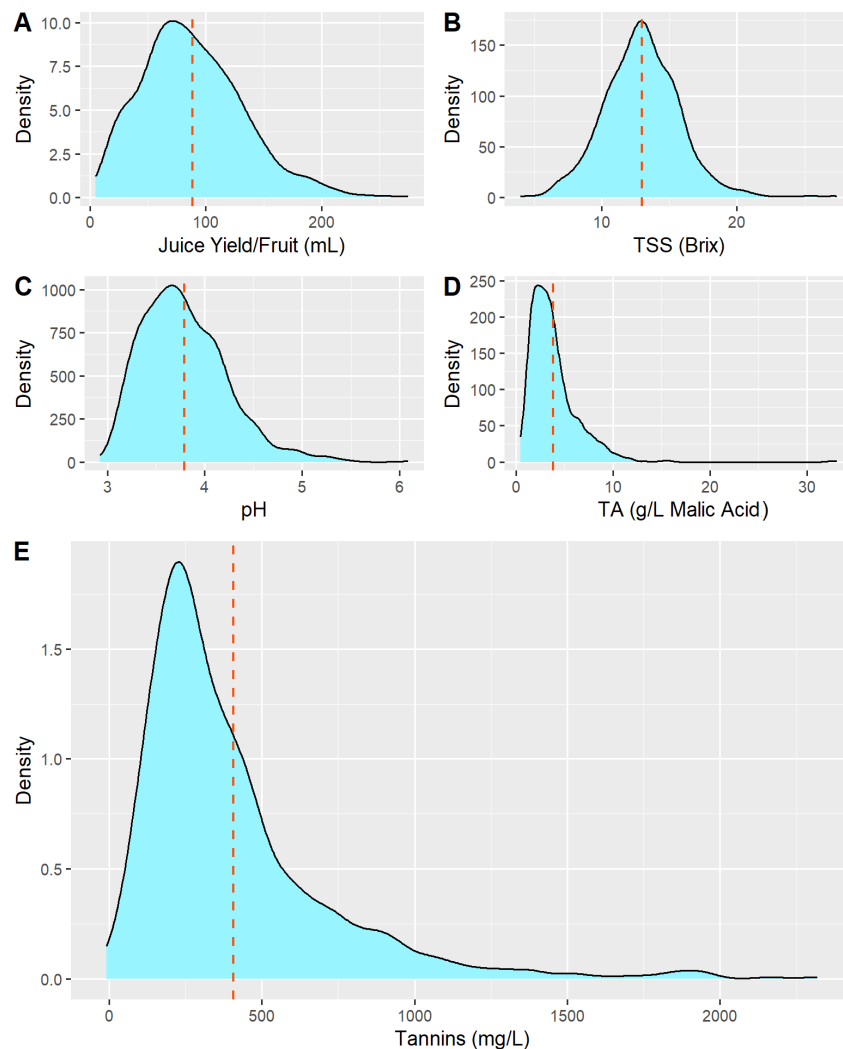


Figure 5. Density plots pear fruit quality metrics A) juice yield in mL/fruit, B) TSS (Brix), C) pH, D) TA (g/L Malic Acid), and E) Tannins (mg/L).

70531-015, US 71643-047, and US 82726-304). Higher acidity has been correlated with consumer preference for increased flavor and, thus, represent desirable genetics already present in the USDA breeding program. Lastly, we documented the variation in tannins (i.e. phenolic) content in this germplasm. Tannins contribute to the bitter and astringent flavor profiles and are generally undesirable. We found the average to be ~400 mg/L within the germplasm (Fig. 5E). The highest recorded tannin contents belong to historic varieties ‘Bellissime d’Hiver’ and ‘Hofrath’s Birne’ at >1300 mg/L. A breeding line that is only a generation or two removed from an interspecific hybridization NJ Rock R21 T227 was the second highest at 1326 mg/L and is recognized as the most bitter fruit in the breeding germplasm. Generally, many of the breeding lines were (35 genotypes) were found to have below the average tannin content. This group included the advance testing line US 79439-004 at 197 mg/L. Other industry standard varieties were also identified as containing <400 mg/L of tannins (‘Comice’, ‘Clapp Favorite’, ‘Gem’, and ‘Bartlett’). This information on fruit quality is invaluable to aiding in the improvement of pear flavor within the breeding program.

Objective 3: Resilience to physical damage during shipping and handling is a critical trait for pear breeding moving forward. Many of the standard varieties currently produced are highly susceptible to scuffling, punctures, and bruising while they traverse the logistics pipeline. To overcome those limitations, we set out to phenotype germplasm to simulated and actual shipping and handling stress. The simulated stress was conducted using the robot arm programmed to simulate trucking (shaking) and drop forces. Here, we evaluated eight replicated fruits from 38 different genotypes. We evaluated the average damage (bruises/fruit, punctures/fruit, and percent compromised/damage severity) for each genotype (Fig. 6A). Over 28 of the evaluated genotypes exhibited some to high susceptibility to damage. However, ten genotypes were found to be resistant with no recorded damage. Of those ten, five were from the same cross/family; US 78302, which is a hybridization of US 56112-146 [US 309 open pollinated] × ‘Madame Ernest Baltet’. We fortunately have one of the grand parents in our

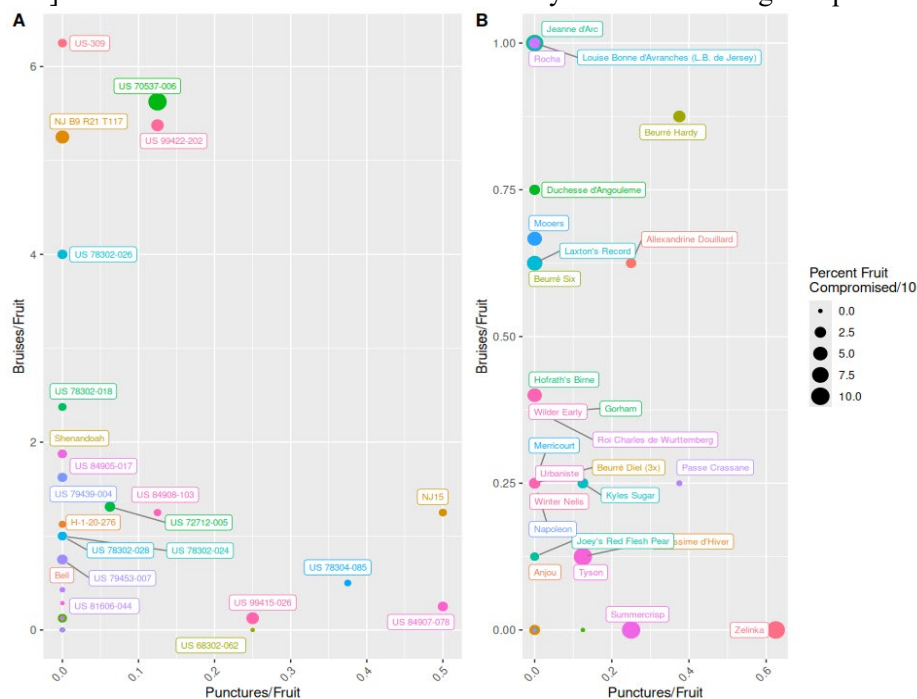


Figure 6. Quantification of bruises, punctures, and percent fruit compromised from A) simulated and B) actual shipping stress. Percent fruit compromised is scaled to 10% of actual values. Fruit with variety names or numbers listed indicate susceptibility to shipping stress.

germplasm (US 309), which exhibited the highest bruising rate observed (**Fig. 6A**). This result suggests that either the unknown pollen parent of the US 56112-146 or ‘Madame Ernest Baltet’ is providing this resistance, if it’s proven to be genetically controlled/influenced. Further study of this important result is needed. We additionally evaluated 34 of the varieties shipped from USDA NCGR for real-world shipping damage (**Fig. 6B**). Of the 34, only six were found to be free of damage. These included ‘Burre Dubuisson’, ‘Buerré Easter’, ‘Clapp Favorite’, ‘Josphine de Malines’, ‘Marie Louise’, and NY 10353. These varieties represent germplasm material that should be further evaluated for genetic potential in providing shipping and handling resiliency.

Objective 4: Publication and dissemination of these results are forthcoming. We anticipate preparing two or three publications that summarize the results of objectives 1 and 2 in the Fall of 2026. One publication will solely focus on the results obtained related to the disease resistant screening. The other one or two publications will focus on the harvest date, conditioning requirements, and fruit quality metrics. All works will be published in open-access journals and notification of publication will be shared with the respective funding associations and committees. Preliminary results from the natural disease incidence and plant pathogen inoculation testing in Objective 1 were presented at the American Phytopathological Society Annual Plant Health Meeting in July 2024, the American Society for Horticultural Science Annual Conference in September 2024, and at the Cumberland-Shenandoah Fruit Workers Conference in December 2024 and December 2025.

Executive Summary

Project title: Germplasm evaluation for fruit quality and post-harvest traits

Key words: pears, germplasm characterization, breeding, disease resistance, supply chain resiliency

Abstract: The USDA pear breeding program has spent 100-plus years breeding for increased disease resistance often to the detriment of fruit quality. Having established strong disease resistance in the breeding program, new breeding directions for the program are to improve fruit quality, post-harvest disease resistance, and resiliency to the supply chain. However, information is lacking on these traits in the breeding program and at the USDA pear collection in Corvallis, OR. To fill this gap in knowledge, we set out to evaluate 50 high potential germplasm lines for harvest date, cold conditioning requirement, post-harvest disease resistance, fruit size and quality, and supply chain resiliency. We surpassed our goals and identified harvest date and conditioning requirements for over 100 historic varieties and breeding lines, resulting in the identification of desirable late harvesting and cold conditioning genotypes. We additionally screened 100 of those genotypes for susceptibility to *Penicillium expansum* and *Colletotrichum fioriniae*. Thirteen genotypes were found to be significantly less susceptible compared to commercial varieties ‘Bartlett’ and ‘Gem’. We have also evaluated over 100 genotypes of pear for fruit size and fruit quality. We identified several varieties of pear with sugar content nearly two-fold higher than the average in the germplasm (~20 or more °Brix). Furthermore, we found the USDA breeding program contains several breeding lines with extremely high acid content, a desirable trait for more flavorful eating experience. Lastly, we evaluated over 50 genotypes for supply chain resiliency. We found a family of breeding lines that were all highly resistant to damage in simulated shipping conditions. The pedigree of that family suggests a historic variety - ‘Madame Ernest Baltet’ - could be a source for that resiliency. These results, ultimately, will guide the breeding program in determining desirable crosses for improving fruit quality and postharvest traits.

Project Title: UV for postharvest decay control in storage and on packingline

Report Type: Continuing Project Report **Year:** 1 of 3

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Cooperators: Sean Naumes, Naumes Inc., Craig Mallon, Duckwall Fruit

Contact information: Qingyang Wang, wangq8@oregonstate.edu, 541-737-7611

Project Duration: 3 Years

Total Project Request for Year 1 Funding: \$59,842

Total Project Request for Year 2 Funding: \$58,807

Total Project Request for Year 3 Funding: \$59,883

Other related/associated funding sources:

1) Oregon State University will in-kind contribute to the tuition of the Graduate Research Assistant hired in this project. 2) Funds from the Washington State specialty Crop Block Grant Program partially cover the cost of a customized UV-conveyor system for lab evaluation and optimization and relevant supplies.

Funding Duration: 1) 2025 – 2027; 2) 2025 – 2027

Amount: 1) \$80,998; 2) \$9,000

Agency Name: 1) Department of Food Science and Technology, Oregon State University, 2) Washington State specialty Crop Block Grant Program

WTFRC Collaborative Costs: None

Budget 1

Primary PI & CO-PI 2: Qingyang Wang & Joy Waite-Cusic*

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Contract Administrator: Irem Turner

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Station Manager/Supervisor: Lisbeth Goddik

Station manager/supervisor email address: lisbeth.goddik@oregonstate.edu

Item	2025	2026	2027
Salaries	\$41,502.00	\$33,280.00	
Benefits	\$12,758.00	\$8,063.00	
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies	\$5,000.00	\$5,000.00	
Travel	\$582.00	\$582.00	\$582.00
Plot Fees			
Miscellaneous			
Total	\$59,842.00	\$46,925.00	\$582.00

Footnotes:

Salaries and Benefits: Salaries are requested for: 1) a Graduate Research Assistant (GRA) at 0.49 FTE at 25.8% benefit rate for Year 1 and Year 2 (Year 1 salaries: \$32,000, Year 1 benefits: \$7,466, Year 2 salaries: \$33,280, Year 2 benefits: \$8,063). Salaries are calculated with an increase of 4% per year, and benefits are calculated with an inflation rate of 8%. 2) an Assistant Professor (base salary \$106,932) at 56.9% benefit rate for 1 month on Year 1 (Year 1 salaries: \$9,502, Year 1 benefits: \$5,292).

Supplies: Funds are requested for purchasing laboratory consumables (such as gloves, centrifuge tubes, and pipette tips), microbiology experiments (such as microbial growth media, Petri dishes, cell-culture plates, sterile supplies).

Travel: Funds are requested to cover the mileage for transportation to WSU/cooperator facility for sample collection and facility visiting once a year adhering to university policies, delineated as \$0.67 per mile × 868 miles = \$581.56

*PI Wang and Co-PI Waite-Cusic will co-advise one GRA and share supplies throughout this project.

Budget 2**Co-PI 3:** Achala N. KC**Organization Name:** Oregon State University – Southern Oregon Research and Extension Center**Contract Administrator:** Josh Kvidt**Telephone:** 541-737-4066**Contract administrator email address:** josh.kvidt@oregonstate.edu**Station Manager/Supervisor:** Alexander Levin**Station manager/supervisor email address:** alexander.levin@oregonstate.edu

Item	2025	2026	2027
Salaries		\$6,297.00	\$21,458.00
Benefits		\$4,785.00	\$10,888.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			\$1,800.00
Travel		\$800.00	\$800.00
Plot Fees			
Miscellaneous			
Total	\$0.00	\$11,882.00	\$34,946.00

Footnotes:

Salaries and Benefits: Salaries are requested for: 1) a Faculty Research Assistant (FRA) at \$49,236/year and 76% benefit rate for 1.5 months on Year 2 and 5 months on Year 3 (Year 2 salaries: \$6,297, Year 2 benefits: \$4,785, Year 3 salaries: \$21,458, Year 3 benefits: \$10,888). Salaries are calculated with an increase of 3% per year, and benefits are calculated with an inflation rate of 3%.

Supplies: Funds are requested for purchasing laboratory consumables and microbiological supplies such as growth media, Petri dishes, inoculation loops, and pipette tips.

Travel: Funds are requested to cover the mileage for transportation to OSU main campus for sample collection and PI meetings on Year 2 and Year 3, delineated as \$0.67 per mile × 398 miles × 3 times per year = \$799.98.

Budget 3**Co-PI 4:** Claire Murphy**Organization:** Washington State University Irrigated Agriculture Research and Extension Center**Contract Administrator:** Hollie Tuttle**Telephone:** 509-786-2226**Contract administrator email address:** prosser.grants@wsu.edu**Station Manager/Supervisor:** Naidu Rayapati**Station manager/supervisor email address:** 509-786-9215

Item	2025	2026	2027
Salaries			\$16,184.00
Benefits			\$1,621.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			\$6,000.00
Travel			\$550.00
Plot Fees			
Miscellaneous			
Total	\$0.00	\$0.00	\$24,355.00

Footnotes:

Salaries and Benefits: Salaries are requested in Year 3 for a graduate student's summer hourly salary and a part-time hourly employee. Benefits are tied to the graduate student's summer hourly salary and salaries as a part-time hourly employee.

Supplies: Funds are requested for purchasing laboratory consumables and microbiological supplies such as growth media, Petri dishes, inoculation loops, and pipette tips.

Travel: Funds are requested to cover the mileage for transportation to cooperator facility for sample collection and facility visiting adhering to university policies, delineated as \$0.67 per mile × 820 miles = \$549.4.

OBJECTIVES

The primary goal of this project is to evaluate and optimize UV-C technology for pear postharvest decay control in two critical operational scenarios: cold storage environments and packing line applications. UV-C is being evaluated for its ability to reduce fungal spore contamination on pears and on common contact surface materials (e.g., plastic and metal surfaces), as well as its capacity to mitigate cross-contamination between contaminated surfaces or fruit and clean pears. In the packing line setting, UV-C also will be assessed as a stand-alone intervention and in combination with secondary antimicrobial sprays (e.g., reduced concentrations of fungicides or sanitizers). This combined approach is intended to address inherent limitations of UV-C related to light dose non-uniformity and surface shadowing, thereby enhancing overall antifungal efficacy. In the optimization phase, this project will examine key engineering and operational parameters of UV-C systems (e.g., lamp positioning, exposure geometry, and dose distribution) to improve treatment efficacy and feasibility for commercial adoption.

- Objective 1. Evaluate the efficacy of UV-C for decontaminating pears and representative contact surface materials, and determine its effectiveness in reducing cross-contamination of fungal pathogens from infected pears or contaminated surfaces to healthy pears.
- Objective 2. Evaluate the effectiveness of UV-C in replacing or complementing fungicide or sanitizer sprays on packing lines using a lab-scale conveyor system, and assess impacts on fungal control and pear quality attributes.
- Objective 3. Validate optimized UV-C treatments from Objectives 1 and 2 under industry-relevant conditions using a simulated bulk cold storage environment and a pilot-scale packing line.

Scope of Year 1 Activities:

This Year 1 progress report primarily addresses Objective 1, with emphasis on the following research questions regarding mechanistic foundation for the use of UV-C as a sanitation tool in pear postharvest environments:

- What are the major fungal transfer pathways during postharvest pear handling, and what is the likelihood of cross-contamination among water, contact surfaces, and pears?
- How effective is UV-C at sanitizing common facility materials and pear skin?
- How does UV-C performance differ between two major postharvest fungal pathogens, *Penicillium expansum* and *Botrytis cinerea*?

SIGNIFICANT FINDINGS

- Fungal cross-contamination during post-harvest pear handling is highly likely; Water can be a major driver of decay spread.
- UV-C is effective for sanitizing facility surfaces, especially for smooth surface.
- Pear skin is more challenging to sanitize with direct UV-C exposure alone; Evaluating the integration of UV-C with other practices (e.g., sanitizer spray) will be the next step.
- Pathogen type matters for UV-C performance; *P. expansum* was consistently more sensitive to UV-C than *B. cinerea*.

METHODS

Experimental Overview: Laboratory-scale experiments were conducted to characterize fungal transfer dynamics, evaluate UV-C sanitation efficacy on representative materials and pear skin, and assess the role of water as a vector for cross-contamination. *Penicillium expansum* and *Botrytis cinerea* were

selected as target pathogens due to their prevalence in pear postharvest decay and differing biological characteristics, including pigmentation and UV tolerance.

Fungal Transfer Between Pears and Facility Surfaces: Bosc pears obtained from retail sources were used in conjunction with stainless steel, PVC, and polystyrene coupons to simulate common postharvest contact surfaces. Surfaces were sterilized with 70% ethanol prior to use. Four transfer sequences were evaluated to represent realistic contact events during postharvest handling: 1) inoculated pear to clean surface, 2) inoculated surface to clean pear, 3) inoculated pear to clean pear, and (4) inoculated pear to surface followed by transfer to a clean pear. Surfaces were inoculated with approximately 10^4 CFU/mL fungal spore suspensions. Transfers were conducted either while surfaces were wet or after drying, depending on the experimental condition. Following transfer, spores were recovered by rinsing in sterile water, plated on potato dextrose agar (PDA), and incubated at 25 °C prior to enumeration.

UV-C Sanitation of Contact Surfaces and Pear Skin: UV-C treatments were conducted using a bench-scale UV-C chamber. Stainless steel coupons, PVC coupons, and pear skin coupons were inoculated with approximately 10^6 CFU of fungal spores and exposed to UV-C doses of 0, 128, or 256 mJ/cm² (equivalent to 0, 30, or 60 seconds of exposure using our lab-scale UV-C chamber). Following treatment, spores were recovered by stomaching or hand massage in sterile rinse solutions, serially diluted, and plated on PDA for enumeration.

Water-Mediated Cross-Contamination Study: To assess the role of water as a contamination vector, visibly *P. expansum*-infected pears were submerged in water to generate a contaminated water source. Healthy pears, both wounded and unwounded, were submerged in the contaminated water for two minutes and subsequently stored under ambient conditions. Disease incidence was evaluated visually over a 10-day period.

RESULTS AND DISCUSSION

Fungal Transfer Pathways and Cross-Contamination Risk: Both *P. expansum* and *B. cinerea* spores were readily transferred between pears and contact surfaces across all evaluated transfer sequences (Figures 1&2). Transfer occurred regardless of surface material or moisture condition, indicating that direct contact alone presents a significant risk for cross-contamination during postharvest handling. These findings confirm that pears, bins, and equipment surfaces can all serve as effective reservoirs and vectors for fungal inoculum. Preliminary observations also suggested that *B. cinerea* spores may adhere more strongly to plastic surfaces compared to metal; however, additional replication is required to confirm material-specific trends.

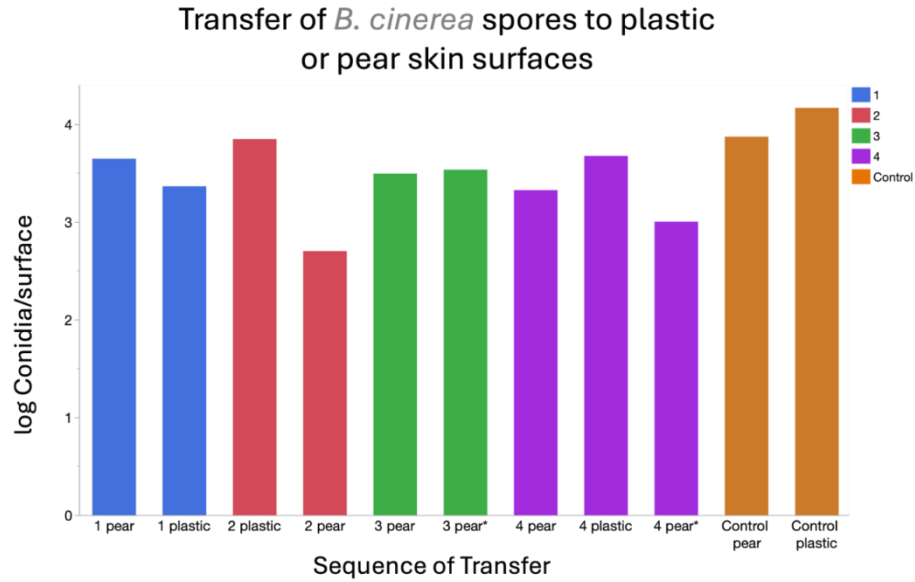


Figure 1. Transfer of *Botrytis cinerea* conidia between pears and contact surface materials (plastic) and between pears. Multiple transfer sequences were evaluated to represent common contact events, including pear-to-surface, surface-to-pear, and pear-to-pear contact.

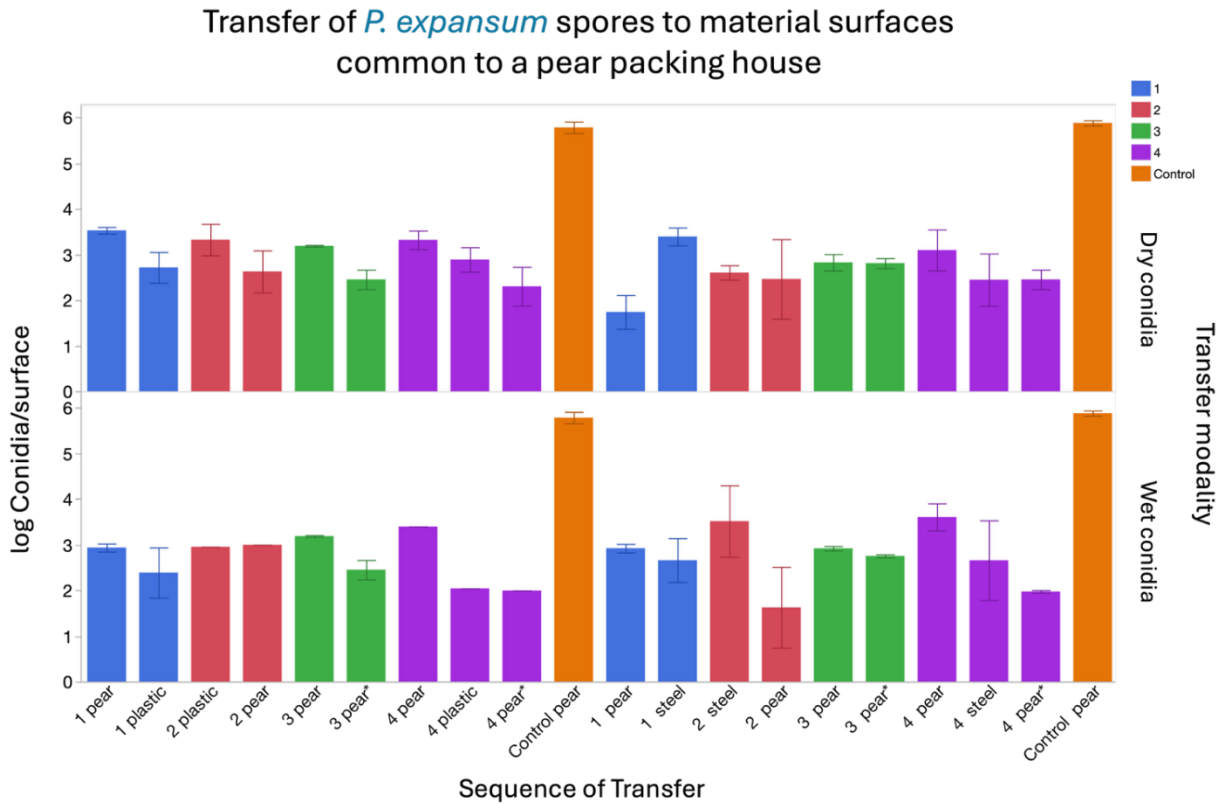


Figure 2. Transfer of *Penicillium expansum* conidia between pears and contact surface materials (plastic and stainless steel) and comparison of fungal spore transfer under wet and dry contact conditions.

Water as a Vector for Postharvest Decay: Water contaminated by diseased pears proved to be a highly effective vehicle for spreading *P. expansum* to healthy fruit. Over 95% of wounded pears and 85% of unwounded pears developed blue mold following brief submersion, with infections frequently originating from natural openings such as lenticels (Figure 3). These findings highlight dunk tanks and shared water systems as critical control points for pear decay management.

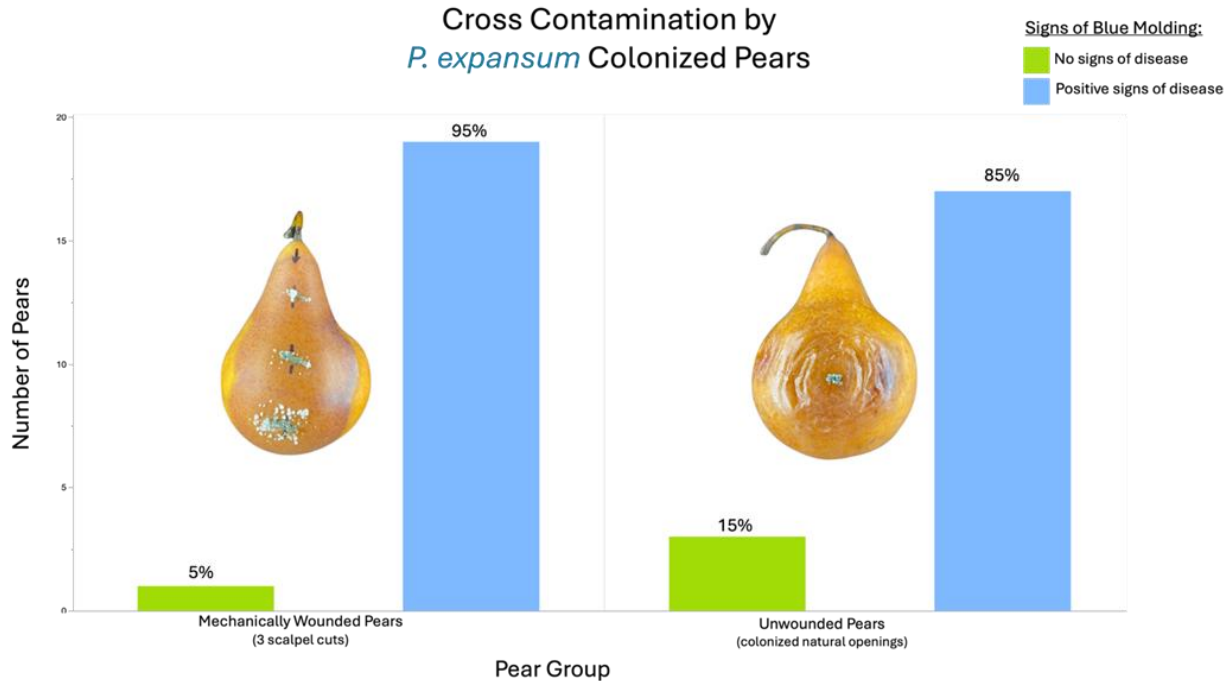


Figure 3. Transfer of fungal spores from diseased pears to healthy pears via bulk water submersion. Incidence of *P. expansum* infection on healthy pears following brief submersion in water contaminated by visibly diseased pears. Both wounded and unwounded pears developed blue mold, with infections frequently originating from natural openings such as lenticels.

UV-C Efficacy on Facility Materials: UV-C treatment significantly reduced fungal populations on both stainless steel and PVC coupons in a dose-dependent manner. Increasing the UV-C dose from 128 to 256 mJ/cm² resulted in statistically significant additional reductions for both pathogens. Across materials, *P. expansum* exhibited greater sensitivity to UV-C than *B. cinerea*, achieving reductions of up to approximately 4.7 log CFU at the highest dose. The greater UV tolerance observed for *B. cinerea* might be attributed to its higher melanin content, which is known to confer protection against UV-induced damage. Stainless steel coupons generally exhibited equal or greater reductions than PVC, likely due to increased reflectivity enhancing effective UV exposure. These results indicate that UV-C is particularly well suited for sanitizing smooth, reflective food-contact surfaces.

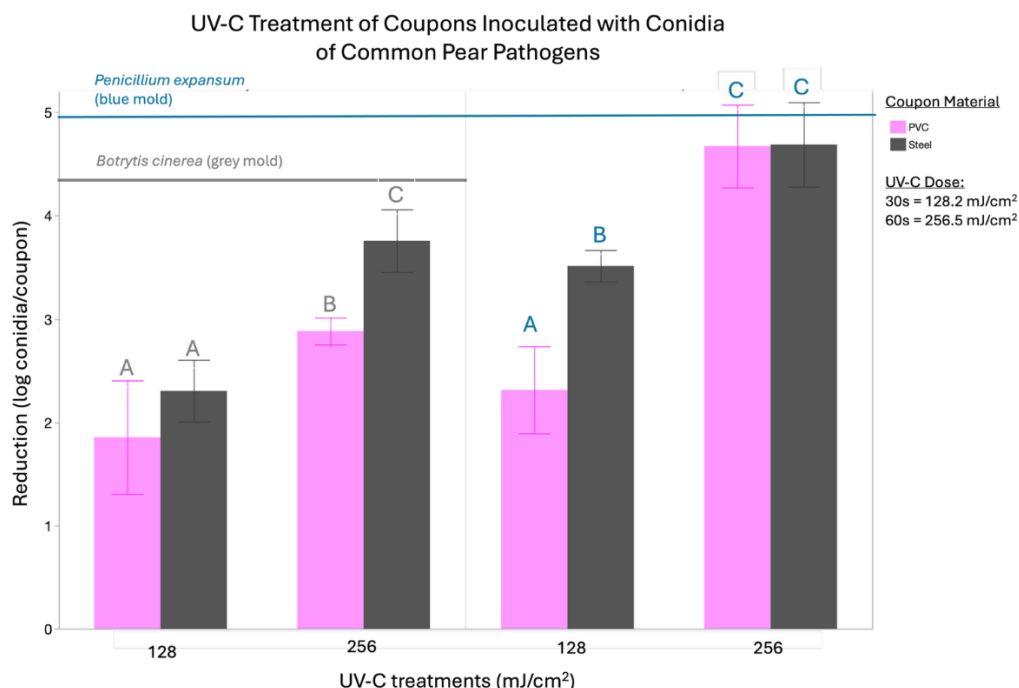


Figure 4. UV-C sanitation efficacy on contact surface materials. Data not connected by the same letter are significantly different (Least Squares Tukey's HSD, $p < 0.05$).

UV-C Sanitation of Pear Skin: UV-C treatment of pear skin resulted in lower average reductions compared to non-biological surfaces, with mean reductions of approximately 1.1 log CFU at 128 mJ/cm² and 2.3 log CFU at 256 mJ/cm². The reduced efficacy on pear skin is attributed to surface roughness, lenticels, and microstructural features that shield spores from direct UV exposure. Despite lower average reductions, individual pear skin samples occasionally achieved reductions comparable to plastic surfaces, suggesting that UV-C can contribute to lowering surface inoculum on pears when integrated with complementary sanitation strategies.

Table 1. Reduction of *B. cinerea* spores on pear skin coupons following UV-C exposure.

UV-C Dose (mJ/cm ²)	Technical Replicate	Conidia Spore Reduction (log CFU/mL)
0	1	0
0	2	0
0	3	0
128.2	1	1.30
128.2	2	1.25
128.2	3	0.73
256.5	1	2.84
256.5	2	1.90
256.5	3	2.10

NEXT STEPS (YEAR 2)

- Expand UV-C efficacy testing to include *Mucor piriformis*.
- Integrate UV-C with complementary interventions (e.g., sanitizer spray) relevant to packing line applications.
- Evaluate shelf life and quality of pears post-treated using a conveyor UV-C system.

Project Title: Assessing and supporting effective areawide pear pest management

Report Type: Continuing Project Report

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Cooperators: Louis Nottingham, Molly Sayles (WSU)

Project Duration: 3 Years

Total Project Request for Year 1 Funding: \$79,989

Total Project Request for Year 2 Funding: \$79,770

Total Project Request for Year 3 Funding: \$77,304

Other related/associated funding sources: *Awarded*

Funding Duration: 2022–2023

Amount: \$40,000

Agency Name: WSU BIOAg Program

Notes: Funded project “Growers’ perceptions of IPM in pear across regions in the Pacific Northwest complements Obj. 1 of this proposal. PIs: Nottingham, Orpet, Sayles

Other related/associated funding sources: *Awarded*

Funding Duration: 2023

Amount: \$29,096

Agency Name: Western SARE

Notes: Funded project “Overcoming Roadblocks to IPM Adoption in Washington Pears” supported Sayles’s involvement in Obj. 2 and associated extension work. PIs: Sayles, Nottingham, Orpet

Other related/associated funding sources: *Awarded*

Funding Duration: 2024

Amount: \$22,314

Agency Name: Washington Commission on Integrated Pest Management

Notes: Funds supported Obj. 2 of this proposal. PI: Orpet

Other related/associated funding sources: *Awarded*

Funding Duration: 2024

Amount: \$15,000

Agency Name: Western IPM Center – Planning Document Grant

Notes: Funds supported Obj. 1 of this proposal. PI: Orpet

Other related/associated funding sources: *Awarded*

Funding Duration: 2024–2026

Amount: \$323,135

Agency Name: USDA Crop Protection & Pest Management

Notes: Funds were to support Obj. 2 of this proposal. PIs: DuPont, Orpet, Adams, Schmidt-Jeffris [Orpet was cut and RT Curtiss added during 2025]

Overall Leveraged Funding for Whole Project Life = \$429,545

Budget 1**Primary PI:** Robert Orpet**Organization Name:** Washington State University**Contract Administrator:** Office of Research Support and Administration**Telephone:** 509-335-9661**Contract administrator email address:** ORSO@wsu.edu**Station Manager/Supervisor:** Kimi Lucas (interim)**Station manager/supervisor email address:** kimi.lucas@wsu.edu

Item	2023	2024	2025
1 Salaries	\$38,250.00	\$39,780.00	\$41,371.00
Benefits	\$11,284.00	\$11,735.00	\$12,204.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
2 Supplies	\$12,100.00		\$4,000.00
3 Travel			
4 Plot Fees	\$9,055.00	\$9,507.00	\$9,959.00
Miscellaneous			
Total	\$70,689.00	\$61,022.00	\$67,534.00

Footnotes:

¹Orpet salary: \$7,083 x 12 mo x 45% (x 1.04 for each additional year), benefits at 29.5%. Funds originally budgeted for Orpet in 2025, will instead be applied to salary of co-PI Curtiss at \$7,083 x 12 mo x 10%, benefits of 32.2% + a Research Intern at \$4,371.44 x 12 mo x 52.75%, benefits of 45.8%

²Supplies: Mailing for 2000 stakeholders = \$10,000 (yr1); materials for extension workshop meetings (\$2,100 yr1, \$4,000 yr3) includes room rental, food, color printing)

⁴Plot fees for WSU Sunrise Research Orchard (\$2,663 per acre X 3.4 acres in year 1, 5% increase for each additional year

Budget 2**Primary PI:** Rebecca Schmidt-Jeffris**Organization Name:** USDA-ARS**Contract Administrator:** Chuck Myers**Telephone:** 510-559-5769**Contract administrator email address:** Chuck.Myers@usda.gov**Station Manager/Supervisor:** Rodney Cooper**Station Manager/Supervisor email Address:** rodney.cooper@usda.gov

Item	2023	2024	2025
Salaries	\$3,523.00	\$7,222.00	\$3,701.00
Benefits	\$1,127.00	\$2,311.00	\$1,184.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			
Travel			
Plot Fees			
Miscellaneous			
Total	\$4,650.00	\$9,533.00	\$4,885.00

Footnotes:

¹GS-6 Biological Science Technician; \$40,262 annual salary, 7 months of work annually at 15% FTE in 2023 and 2025 and 30% FTE in 2024, with 32% fringe rate and COLA for Year 2 and 3 at 2.5%.

Budget 3**Primary PI:** Chris Adams**Organization Name:** OSU**Contract Administrator:** Charlene Wilkinson**Telephone:** 541-737-3228**Contract administrator email address:** charlene.wilkinson@oregonstate.edu

Item	2023	2024	2025
Salaries	\$3,523.00	\$6,981.00	\$3,701.00
Benefits	\$1,127.00	\$2,234.00	\$1,184.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			
Travel			
Plot Fees			
Miscellaneous			
Total	\$4,650.00	\$9,215.00	\$4,885.00

Footnotes:

¹Technician; \$40,262 annual salary, 7 months of work annually at 15% FTE in 2023 and 2025 and 29% FTE in 2024, with 32% fringe rate and COLA for Year 2 and 3 at 2.5%

Original Objectives and Significant Findings

1. *Conduct an industry-wide pear grower and consultant survey of pest management practices.*

- Data from growers for the year 2024 were analyzed for the entire pacific region (BC, WA, OR, CA), but response rates from consultants were too low for useful analysis.
- Wenatchee district growers had relatively low use of codling moth mating disruption, used the most insecticides, and had the greatest pear psylla problem.
- Growers in CA, Yakima, and BC used the fewest insecticides and had low pear psylla problems. Hood River and Okanogan were intermediate, but closer to Wenatchee in these metrics.
- Reported occurrence of rust mites was highest in BC and decreased latitudinally to CA; spider mites were sporadic across the whole region. Average occurrence of spider mites within a district was unrelated to total miticide applications.
- The reported importance of consultants from chemical distribution companies increased over the last two decades, while the importance of private consultants and extension declined.

2. *Evaluate and share outcomes of IPM program trials in Wenatchee, Yakima, and Hood River*

- Growers trialing IPM in Wenatchee replaced almost all use of “harsh” biocontrol-incompatible sprays with “IPM” options while achieving similar pear psylla control, although pear psylla damage was highly variable between locations and years.
- Insecticide and miticide materials costs per acre from grower spray records in Wenatchee from 2022–2024 averaged \$1446 in standard vs. \$1124 in IPM plots (\$322 less with IPM).
- Plots managed by commercial growers in Hood River and Yakima did not strictly follow the IPM guidelines used in Wenatchee, but used fewer insecticides, so are here termed “blended”.
- Hood River pear psylla dynamics and spray programs resembled Wenatchee programs more closely than assumed when this project was conceived.
- Yakima pear orchards had relatively low pear psylla, but could still experience damage at times.
- *Pear Entomology Weekly*, co-edited by Orpet and Sayles from 2023 – April 1, 2025, shared weekly in-season monitoring data across districts, pear psylla degree-days, and IPM guidelines with over 200 subscribers. After April 1, 2025, a similar report was coordinated by DuPont while Orpet contributed summary degree-day and insect population dynamics graphics.
- Funds from this project were used and leveraged by DuPont and by Sayles for additional grants supporting extension in Washington: Study Circles (two in 2023; 140 participants), a Pear Pest Management Discussion Group (four in 2023, three in 2024; four in 2025), panels at the NW Hort Expo and the NCW Pear Day, and a field day each year. Most participants, if surveyed at an event, reported learning something and planning to change at least one practice.
- Wenatchee growers increased adoption of IPM. In 2024, two of the six standard plots on the project switched to IPM, so monitoring was expanded to include replacement standard plots managed by neighbors. In 2025, three of the six standard plots switched to IPM, so the project expanded again with replacements.
- Standard plots always had very high pear psylla abundance in fall relative to IPM plots, but each spring the adult populations were similar regardless of management, suggesting standard spray programs generate large overwintering populations that spread across their district.

3. *Quantify correlations between IPM outcomes with landscape factors*

- Within the Wenatchee district, we found no correlations between local landscape factors (e.g., percentage pear surrounding study plots) with spring pear psylla populations, natural enemies, or fruit damage.
- Considering the observations and the biology of natural enemies, it is possible that the main source of natural enemies in a pear plot is the pear plot itself.
- Comparing districts, higher pear psylla damage was correlated with higher pesticide use, higher acreage of pear, and the Anjou cultivar.

Results and Discussion

Objective 1: an industry-wide pear grower and consultant survey of pest management practices

A subset of results from a 26-question survey are summarized below. A more detailed eight-page paper was prepared by Orpet, Sayles, Curtiss, Adams, and Goldberger entitled “Status of pear insect and mite management in western North America, 2024”, submitted to the Proceedings of the International Organization for Biocontrol (*in review*). A pre-print is available by request to Orpet.

Methods. In January 2025, 2,205 people received the survey by mail, e-mail, or both. Administration was done by the Washington State University Social and Economic Sciences Research Center. The Washington State University Institutional Review Board determined exemption from federal regulations on human subjects (IRB# 20391-001). Most questions asked respondents to consider the last three years, to avoid bias from unusual years. Responses from owners, lessees, or hired managers were analyzed. People with under 1 acre of pear were excluded, resulting in 32 exclusions and 130 usable responses, summarized by geographic district in Table 1. They represented 11,930 acres, which is about 27% of the regional acreage. Responses from consultants were not analyzed because there were only 13 usable responses, precluding plausible comparison of variation in practices between districts.

Table 1. Number of usable responses (N) by district with the sum, median (\tilde{x}), mean (\bar{x}), and standard deviation (SD) of reported acres. The same are reported for organic acreage (certified and in transition) and the number of people with 100% of their acreage organic (N 100%).

District	Total acres					Organic acres only					
	N	Sum	\tilde{x}	\bar{x}	SD	N	Sum	\tilde{x}	\bar{x}	SD	N 100%
CA: River	7	2179	7	311	571	3	109	5	37	54	3
CA: Mountain	7	484	47	69	47	1	18	18	18	0	0
CA: Other	4	158	4	40	74	3	37	4	13	15	2
OR: Hood River	46	5417	99	119	96	8	119	10	15	16	3
OR: Other	3	94	32	32	9	0	0	0	0	0	0
WA: Yakima	14	739	30	52	52	4	42	9	10	5	1
WA: Wenatchee	20	1324	47	67	77	8	185	17	23	22	2
WA: Okanogan	11	558	44	52	54	6	252	10	42	77	2
WA: Other	12	899	9	74	227	7	242	6	35	74	5
British Columbia	6	72	4	12	19	1	4	4	4	4	1
ALL:	130	11930	47	91	168	41	1008	25	59	106	19

Pest occurrence. The pests most often reported to cause damage were pear psylla, codling moth, stink bugs, rust mite, and spider mite. Pear psylla was least reported in British Columbia, Yakima, and California. Codling moth occurrence was lowest in British Columbia. Stink bugs were not reported in Yakima. There was a latitudinal gradient with increasing rust mite with northernliness. Leafrollers and thrips damage was most common in British Columbia.

Pesticides. One-hundred respondents inputted a pesticide record for a representative block in 2024. A total of 47 insecticide and miticide active ingredients were identified. For analysis they were grouped into working categories of “harsh”, “IPM”, and “miticide” (Table 2). The “harsh” ingredients are considered likely disruptive to biocontrol. The “IPM” ingredients are those considered permissible in the Washington

State University pear IPM guidelines used in objective 2 of this report. The 10 most-used ingredients across the Pacific region were (in descending order): mineral oil, mancozeb, spirotetramat, kaolin, sulfur, azadirachtin, abamectin, chlorantraniliprole, pyriproxyfen, and codling moth virus (Table 2).

Frequencies varied across districts (Figure 1). The average number of ingredients applied in 2024 ranged from 5.8 in British Columbia to 22.3 in Wenatchee. Particle films (e.g., kaolin) were only reported in Washington and Oregon. There was not much between-district variation in the number of “harsh” ingredients used, with 2–3 applications being generally reported. In Wenatchee, half of respondents reported they sprayed less than usual in 2024 (low fruit set and frost damage resulted in many blocks not being harvested), but in other districts the ratio of people spraying less vs. more was balanced (Figure 2A).

Table 2. Insecticide and miticide ingredients (and mean no. of applications) from 100 spray records from the year 2024. Categories “harsh” and “IPM” are judgements of unsuitability or suitability in programs meant to conserve insect biological control. “Miticide” ingredients are mainly used for mites

Category	Sub-category	Ingredient
Harsh	Neonicotinoid	Acetamiprid (0.23), imidacloprid (0.08), thiamethoxam (0.03)
	Pyrethroid	Beta-cyfluthrin (0.01), lambda-cyhalothrin (0.08), pyrethrins (0.01), zeta-cypermethrin (0.01)
	Other	Abamectin (0.56), carbaryl (0.01), cyantraniliprole (0.02), cyclaniliprole (0.01), diazinon (0.01), esfenvalerate (0.01), malathion (0.12), novaluron (0.16), spinetoram (0.25), spinosad (0.06), sulfoxaflor (0.03), tolfenpyrad (0.27)
IPM	Selective	<i>Bacillus thuringiensis</i> (0.17), codling moth virus (0.49)
	Particle	CaCO ₃ (0.31), diatomaceous earth (0.10), kaolin (0.83)
	Other	Azadirachtin (0.71), botanical oil (0.24), buprofezin (0.19), chlorantraniliprole (0.52), cinnamon oil (0.21), diflubenzuron (0.03), fish oil (0.01), lime sulfur (0.37), mancozeb (0.88), methoxyfenozide (0.13), mineral oil (3.95), potassium laurate (0.02), pyriproxyfen (0.49), spirotetramat (0.87), sulfur (0.74)
Miticide	--	Bifenazate (0.03), cyflumetofen (0.14), etoxazole (0.08), fenazaquin (0.12), fenbutatin-oxide (0.08), pyridaben (0.27), spirotetramat (0.22)

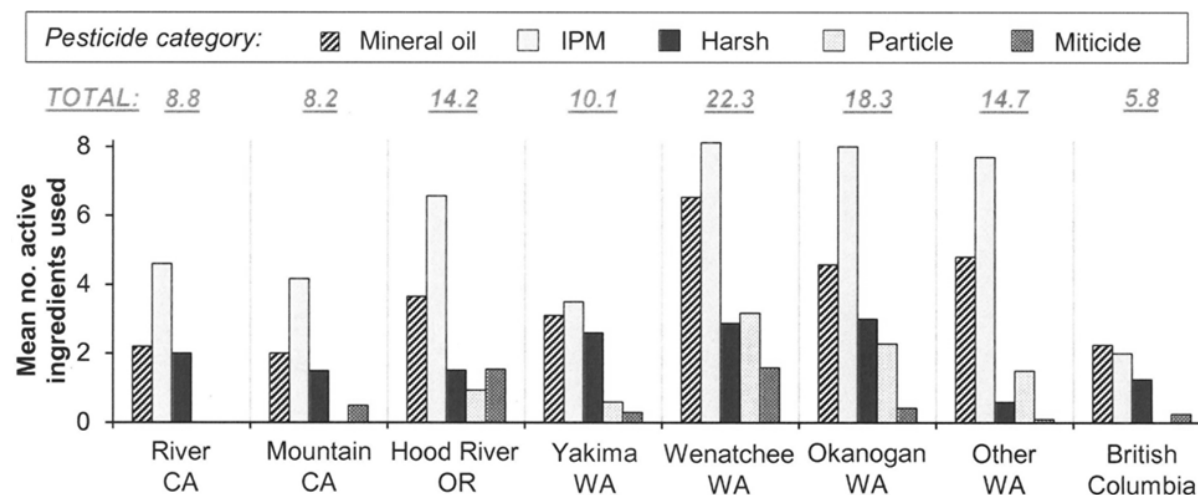


Figure 1. The mean number of pesticide ingredients used across districts in 2024.

Pesticide-pest correlations. There was a positive correlation between the mean percentage of pears damaged by pear psylla with the mean number of insecticides and miticides used (Figure 2B). There was no correlation when only “harsh” (Table 2) pesticides were analyzed ($P = 0.55$, $R^2 = 0.06$). There was no significant correlation between spider mite damage with pesticide use ($P = 0.46$, $R^2 = 0.09$; miticides only: $P = 0.54$, $R^2 = 0.06$).

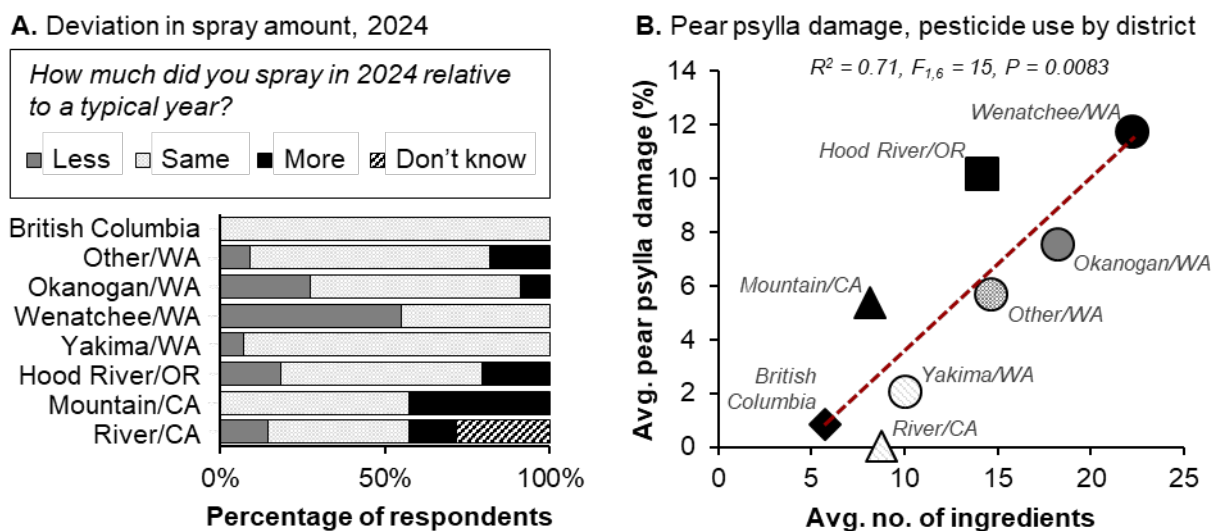


Figure 2. District mean percentage pears damaged (downgraded or culled) by pear psylla 2022–2024 by average no. of 2024 insecticides and miticides 2024 (A) and answers to the question “how much did you spray insecticides and miticides in 2024 relative to a typical year?” (B).

Other pest management practices. The number of growers reporting to use codling moth mating disruption on all of their pear acres was decisively the lowest in Wenatchee (30%). The percentages for other districts were: British Columbia (50%); Hood River (56%), Okanogan (63%) and all others (71–100%). Almost all growers reported using a codling moth degree-day model. Over 75% of Oregon and Washington growers reported using a pear psylla degree-day model. Among growers using models, Washington State University’s Decision Aid System website was used in Washington (70%), British Columbia (100%), and Oregon (24%). The website USPest.org was used in Oregon (41%), and Washington (13%). The balance and sources in other districts were from extension activity, other websites, or private sources. Consultants from chemical distribution companies were most often rated as very important to help make pest management decisions.

Relevance. Reports from the 1990s suggest that pear growers of California and British Columbia reduced insecticide use to a third of previous levels by adopting integrated management programs based on codling moth mating disruption and organophosphate alternatives. By integrating biocontrol, these programs also reportedly reduced pear psylla and mite problems. The survey results show these changes have been durable. Meanwhile, use of insecticides and miticides doubled in Washington since the 1990s¹ and use of

¹Compare current results with: Brunner, JF, J Dunley, W Jones, E Beers, GV Tangren, C Xiao and GG Grove. 2003. Pesticide use and IPM practices in Washington’s pear and cherry orchards. *Agri. & Environ. News*. <https://web.archive.org/web/20250421141833/http://aenews.wsu.edu/Aug03AENews/Aug03AENews.htm#PearCherry>

mating disruption is low in Wenatchee. The survey indicates that Yakima pear pest management resembles that of California more than the rest of Washington. Hood River is intermediate. In Hood River, reported pesticide use and pear psylla were higher than we had assumed when originally designing this research. The results put into context that an integrated management program characterized by relatively low insecticide use and low pear psylla has been accomplished long-term in several districts.

Limitations and reflections. These results fill in a missing gap where we had recently assumed patterns based on anecdotes and decades-old reports. The probability-based survey design used here was useful and allows for comparison with older surveys¹ and between districts. However, low response rates increase the risk of bias, and districts with fewer growers were unrepresented. For this research, a separate survey was designed for consultants, but there were few responses. Greater communication and buy-in could have improved response rates, but in retrospect a much shorter survey or other evaluation method for consultants would have been more effective. To increase response rates more generally, a future survey should be shorter to make it easier to respond. In addition, fewer surveys should be done overall to reduce survey fatigue. Needs assessments and project evaluations should be planned more carefully to avoid redundancy, improve validity, and consider benefits to the community. The input of a sociologist and the professional services of the Washington State University Social and Economic Sciences Research Center on this project were essential.

Objective 2. Outcomes of IPM program trials in Wenatchee, Yakima, and Hood River

A summary of key findings is given below. Results from Wenatchee in 2022–2024 are given in greater detail in an eight-page paper, entitled “Implementing a new integrated pest management program for pear pests in Washington State, USA” submitted to the Proceedings of the International Organization for Biocontrol (*in review*). A pre-print is available by request to Orpet.

Support for IPM implementation. In 2023, a weekly internal report to growers and consultants in Wenatchee during 2022 was expanded into a public newsletter called Pear Entomology Weekly. The newsletter shared pear psylla degree-days, IPM guidelines, and scouting data by plot. It reached 224 subscribers by the end of 2024. Orpet and Sayles co-edited 79 issues until April 1, 2025, after which time Orpet served as a contributor, providing summary charts from Wenatchee, Yakima, Hood River, and Southern Oregon. For a standing reference, the WSU “Pear Psylla Phenology Model” website was updated in 2024 (<https://treefruit.wsu.edu/crop-protection/psylla-phenology-model/>). This website contains pear IPM guidelines on a degree-day basis. The guidelines are summarized here in Figure 3. Pear psylla degree-days can be obtained on <http://USPEST.org> for free or <https://decisionaid.systems> a subscription fee.

Evaluation and data sources. In 2022, a pear IPM project in the Wenatchee Valley was initiated by Nottingham and Orpet. The current project extended it into 2023–2025 and added plots in Yakima and Hood River. In Wenatchee, seven pairs of commercial orchards (one plot using standard management and one nearby plot following the new IPM program) were monitored for pests, beneficials, and fruit damage in 2022. Six of the same pairs were used in 2023–2025 and one was dropped because the grower could not be contacted. In 2024 and 2025, standard plots sometimes switched to IPM programs, so replacement standard plots were sourced, but the number of pairs was reduced to five in 2025 since a replacement could not be found for one location. For Yakima and Hood River, the current project included scouting of four plots each during 2024 and 2025. In 2025, two additional plots were added to each district using a new USDA grant to Tianna DuPont for the “Scouting Network”. In 2025, Orpet added three plots from the Southern Oregon Research and Extension Center. Monitoring in all years included standard methods of weekly beat tray taps

(generally 25 per plot) and leaf brush samples (50–100 leaves per plot, taking 5 leaves per shoot from an equal mix of high and low first-year growth).

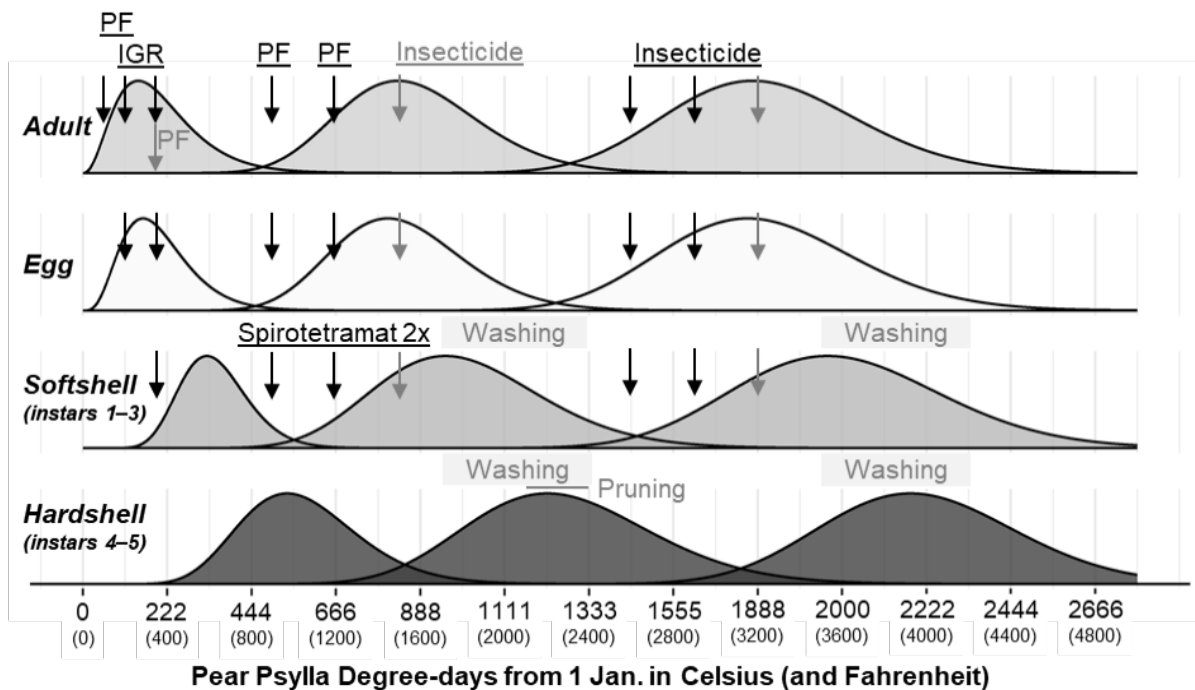


Figure 3. Pear IPM guidelines on a pear psylla degree-day basis. Each curve shows a gamma probability density function (from Jones et al.) predicting relative abundance of a given life stage and generation. Arrows or boxes show timings for IPM techniques (gray are considered optional); PF = particle film to deter adults and egg lay; IGR = insect growth regulator; spirotetramat can be used two times within the shown range; insecticide = various other options within the guidelines.

Results – Wenatchee Valley. There was no statistical difference in pear psylla pear downgrades between standard and IPM in Wenatchee Valley plots any year, but the P value was marginal (0.051) for higher IPM Anjou damage in 2024 (Table 3). At the Rock Island pair of plots (excluded from Wenatchee Valley comparisons), pear psylla downgrades were higher in the standard management plot three out of the four years (Table 3), but there was no statistical analysis due to lack of replication of plots at this location.

The IPM spray programs costed less than standard programs overall, but costs by year were significantly lower only in 2023 (Table 4). The IPM programs excluded all “harsh” chemicals listed in Table 2 except for some growers who chose, in the prebloom period, to use malathion, tolfenpyrad, or abamectin. The IPM programs had a mean number of 7.9 spray events involving insecticides or miticide per year and 23 uses of insecticide or miticide ingredients. The most commonly used materials with IPM programs were mineral oil, kaolin, azadirachtin (or neem oil), pyriproxyfen, spirotetramat, cinnamon oil, and sulfur. The standard programs had a mean number of 8.4 spray events and 28 ingredients. The most commonly used materials under standard programs were mineral oil, kaolin, spirotetramat, abamectin, acetamiprid, imidacloprid, malathion, novaluron, spinetoram, tolfenpyrad, thiamethoxam, and cyflumetofen. Codling moth mating disruption costs are not included in Table 3 and were not analyzed due to inconsistent documentation; it would cost \$125–240/acre in materials if used.

Table 3. Mean (SD) percentage ‘Anjou’ downgraded from pear psylla at plots across Washington and Oregon districts monitored in 2022–2025.

Location	Year	Percentage downgraded			Paired t-test
		Blended	Standard	IPM	
Wenatchee Valley	2022	-	8.43 (3.4)	11.4 (8.8)	T = -0.76, df = 6, P = 0.48
	2023	-	4.17 (6.9)	0.50 (1.2)	T = 1.23, df = 5, P = 0.27
	2024	-	15.8 (21)	23.4 (24)	T = -2.56, df = 5, P = 0.05
	2025	-	0.90 (1.2)	1.50 (1.6)	T = 0.47, df = 4, P = 0.66
Rock Island	2022	-	2.00	0	-
	2023	-	10.0	1.00	-
	2024	-	3.00	6.00	-
	2025	-	17.0	12.5	-
Yakima	2024	18.1 (11.5)	-	-	-
	2025	-	-	-	-
Hood River	2024	0.25 (0.4)	-	-	-
	2025	3.92 (2.8)	-	-	-
Southern Oregon	2025	-	0	0	-

Table 4. Mean (with range, and standard deviation) of per acre insecticide and miticide materials costs for standard and IPM plots in Wenatchee Valley project plots. To calculate chemical control materials costs, list prices of all insecticide and miticide products found in spray records were obtained from five chemical distributors and averaged for calculations.

Year	Mean materials cost per acre (range, SD)			Paired t-test
	Standard	IPM		
2022	\$1462 (856–2059, 477)	\$1517 (1162–2178, 409)		T = -0.44, df = 5, P = 0.68
2023	\$1563 (1166–1924, 268)	\$1082 (618–1425, 302)		T = 2.66, df = 5, P = 0.045
2024	\$1312 (871–1768, 402)	\$1124 (716–1611, 295)		T = 1.09, df = 5, P = 0.32
<i>MEAN:</i>	<i>\$1446 (1058–1876, 318)</i>	<i>\$1241 (1029–1431, 149)</i>		<i>T = 1.87, df = 5, P = 0.12</i>

Pear psylla tended to be found in similar abundance between standard and IPM plots in spring, higher in IPM in summer, and higher in standard plots in late summer through fall. Standard plots often had over 10 times more pear psylla adults than IPM plots in fall (Figure 4). *Trechnites* parasitoids, *Campylomma* bugs, and *Deraeocoris* bugs responded to pear psylla. *Trechnites* were hardly found under standard programs (Figure 5). *Campylomma* and *Deraeocoris* were sometimes found under standard programs later in the season (Figure 5). Green lacewing and coccinellidae (ladybug) occurrences were not highly associated with pear psylla and were found in similar amounts under both management programs.

There was no clear difference in rust mites or spider mites populations between IPM and standard plots. They occurred sporadically, and *Typhlodromus* predator mites tracked spider mites regardless of management program.

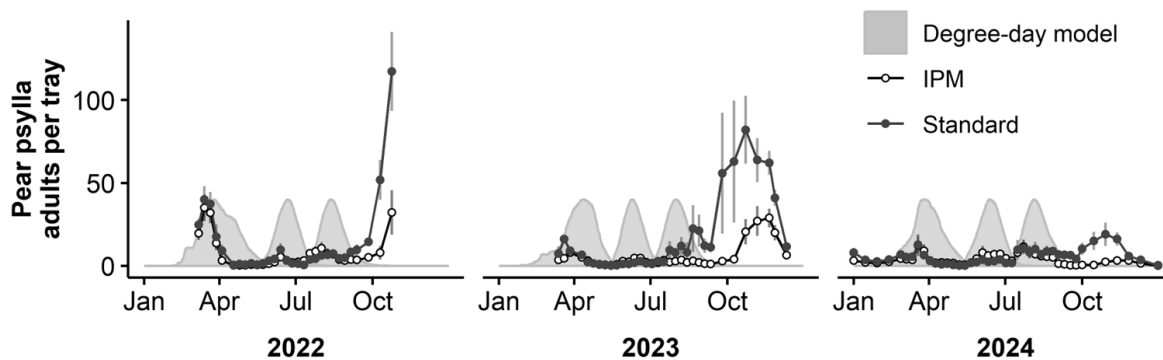


Figure 4. Weekly mean (\pm SEM) pear psylla adults per tap in standard and IPM pear plots (N = 7 pairs, 2022; N = 6 pairs, 2023–2024). The shaded area depicting the degree-model has an arbitrary height and is meant to show the predicted timing of insects, not the amount.

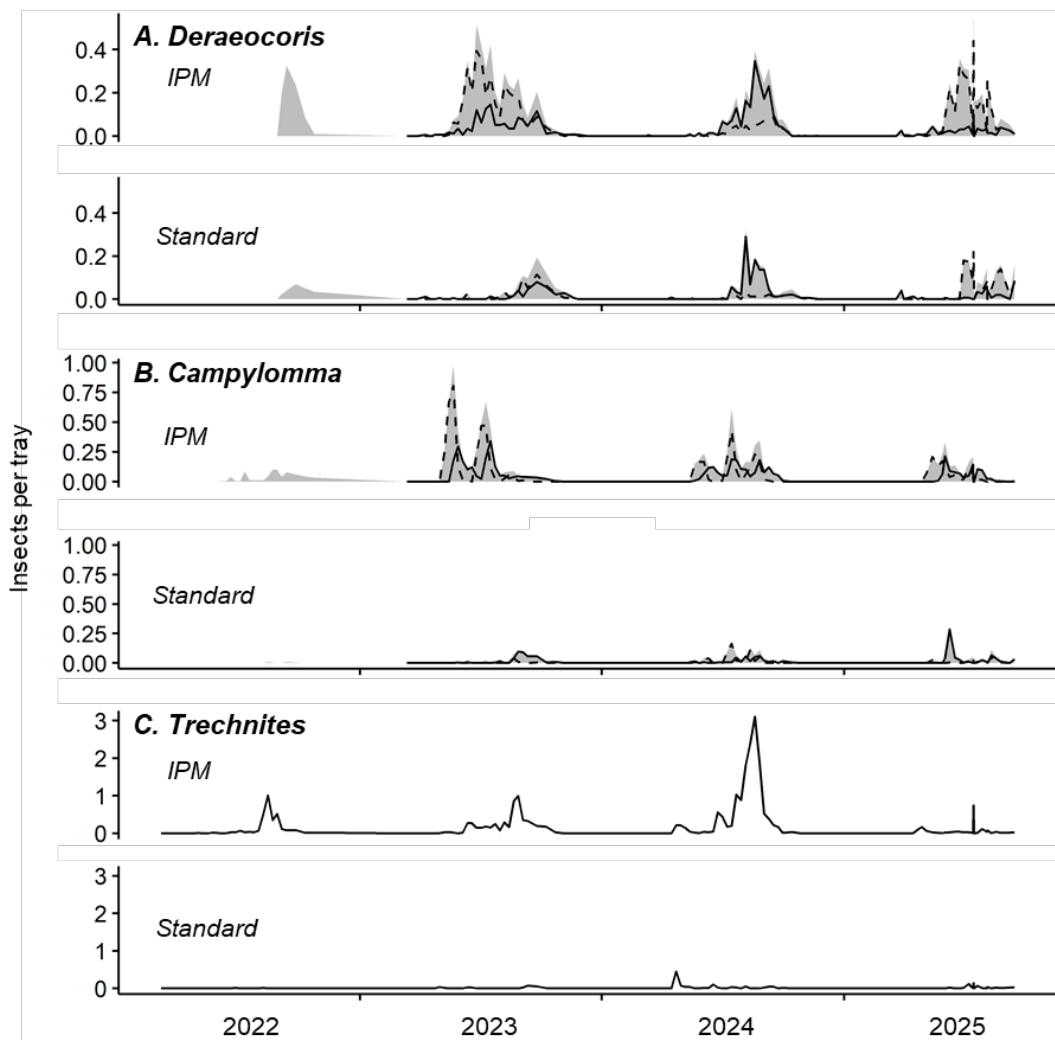


Figure 5. Weekly mean natural enemies per tap in standard and IPM pear plots (N = 7 pairs, 2022; N = 6 pairs, 2023–2024, N = 5 pairs, 2025). Grey areas show the total, solid black show adults, and dashed black show nymphs (nymphs and adults were not distinguished in 2022).

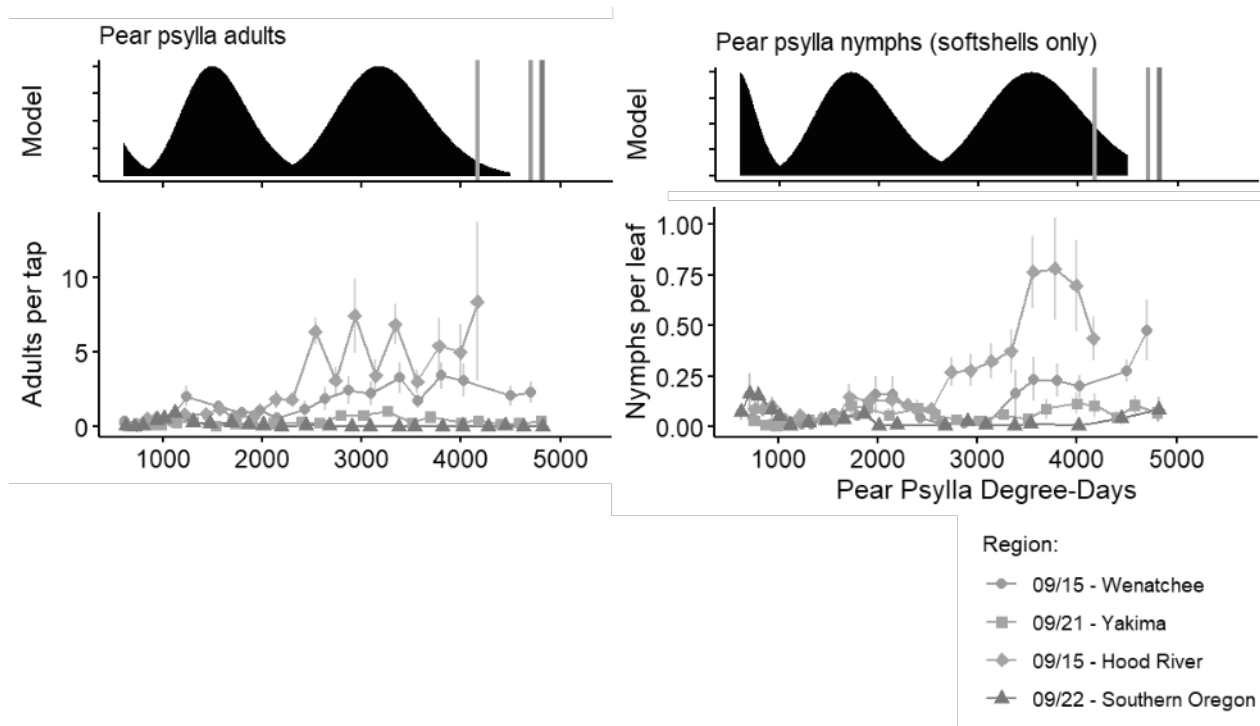


Figure 6. Weekly sampling of pear psylla adults and softshell nymphs (instars 1–3) on a degree-day scale below model predictions of relative abundance. The key also shows the final day of sampling in 2025 for each pear region. In the color version shared in Pear Entomology Weekly, colored vertical bars in the top portion would visualize where each region was on the model, progressing each week.

Results – District-level comparisons. Pear psylla adults and softshell nymphs (instars 1–3) are graphed on a degree-day basis during 2025 in four pear-growing districts in Figure 6, which is an example of a summary figure used in the Pear Entomology Weekly newsletter in 2025. Wenatchee and Hood River had higher populations than Yakima and Southern Oregon plots. All regions reasonably followed the pear psylla model prediction of relative abundance.

Natural enemy abundance and diversity across the 2025 season are visualized in Figure 7. Although Wenatchee and Hood River had high numbers of *Trechnites*, *Deraeocoris*, and *Campylomma*, this was in response to higher pear psylla populations. Thus the ratio of natural enemies to pear psylla was less favorable than in Yakima. Southern Oregon plots had few pear psylla and a community of generalists like ladybugs, lacewings and earwigs. Wenatchee was notable in having few earwigs compared with other districts.

Relevance. Attitudes and practices about pear pest management changed during this project. In 2022, we felt that the growers and consultants trialling the IPM program were innovators and early adopters. However, through extension activities and communication within the community, the IPM idea gained interest. In 2025, we had difficulty sourcing new standard plots to replace ones that were switching to IPM spray programs. Growers on the project increasing their IPM is a strong indication that the program is working. Nonetheless, insecticide and miticide use in the Wenatchee IPM plots we studied was higher than the mean usage of any other district reported in the survey from Objective 1. Wenatchee IPM plots did not greatly reduce pesticide use relative to standard plots, but rather substituted harsh sprays with azadiacthin and cinnamon oil while using near-maximum intensity of IPM-permissible ingredients like spirotetramat, pyriproxyfen, and kaolin.

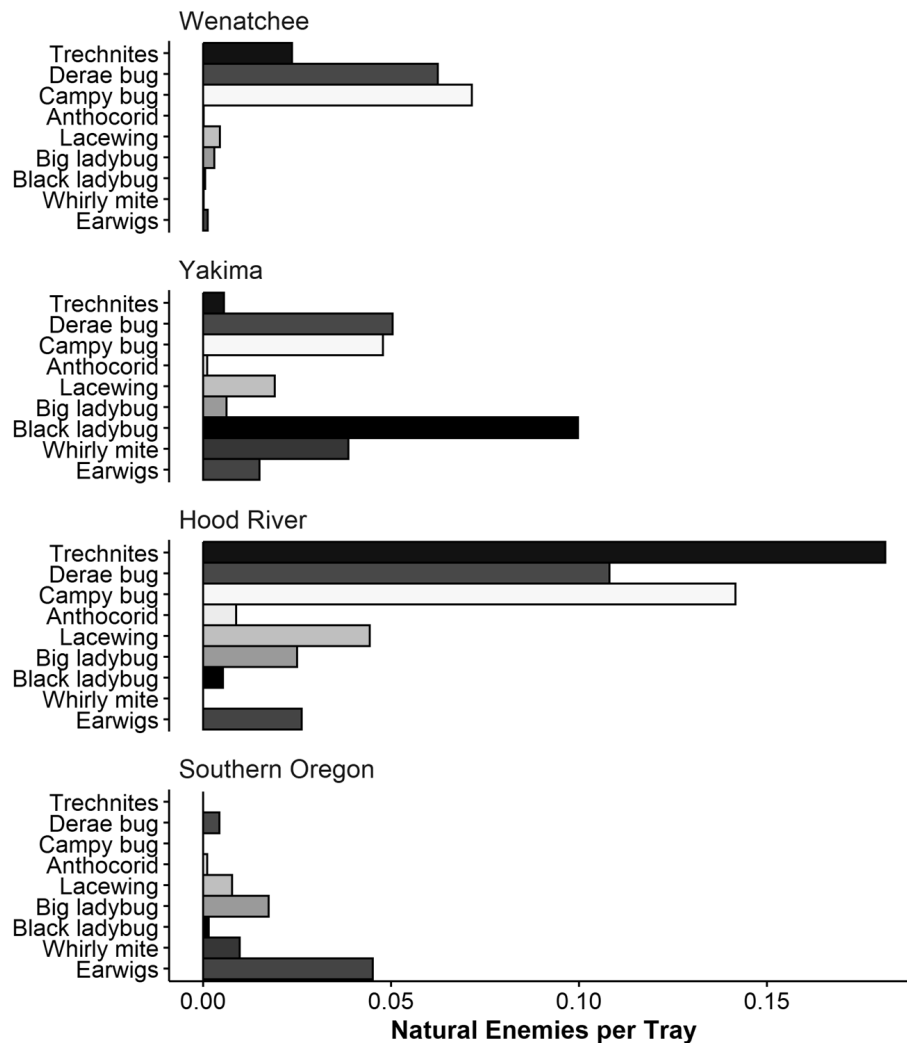


Figure 7. Natural enemies per tray across the entire 2025 growing season for four pear districts.

Limitations and reflections. A lack of control over pesticide programs in commercial plots, especially in Yakima and Hood River, limited evaluation of standard vs. IPM in different districts. The paired plot design in Wenatchee was successful, but higher replication would have been useful since there was so much variation. Sometimes standard plots had less pear psylla damage, and sometimes IPM had less. Future evaluations of pear IPM could attempt to study more plots, and attempt to have greater understanding or control of spray programs in carefully selected pairs.

Objective 3. Quantify correlations between IPM outcomes with landscape factors

This analysis used the data from Objective 2 to search for correlations between landscape factors with IPM program outcomes. It was thought that being next to more pears would decrease IPM program effectiveness in a plot due to close access to dispersive overwintering pear psylla adults and less accessibility to refuges of natural enemies.

Methods. A map of the Wenatchee Valley pear landscape was created with QGIS software. A base map of satellite imagery from Esri and polygons for different categories of land use were manually annotated. Categories included pear, other tree fruit (apple, cherry, peach), grape, open water (used for the Wenatchee River and parts and Peshastin Creek), creek or riparian (used for smaller creeks and buffer of apparent riparian vegetation around water), canal (including the canal and buffer of associated vegetation), developed (roads with roadsides; residential, commercial, and industrial lots), open fields or grassland, forest, and shrubland. The USDA Cropscape Website and Google Earth were used for assistance identifying most likely land use category. Organic pears (certified or in transition) were coded separately from conventional pears according to public data supplied by Washington State Department of Agriculture. The year 2023 was used as the reference point since it was not practical to generate a separate map for each year. Percentages of different land use categories were calculated within a 500-m radius around the central points of Wenatchee study sites from Objective 2 (Figure 8). Various correlations between land use and insect data were explored.

Results – Wenatchee correlations. There was not a significant effect of percentage of pears surrounding plots on peak spring pear psylla abundance in any year for IPM or standard plots. There was high variation between plots and years. For example, the most isolated plot in Wenatchee Valley studied here (Figure 9, HWY 97) had peak spring populations varying at 32, 8.7, 44, and 6.4 per tray in 2022, 2023, 2024, and 2025, respectively, despite supporting low pear psylla population each summer (there were 0, 0, 6.5, and 0.5 percentage pear psylla downgrades in those years at the plot). In contrast, spring pear psylla populations at WSU Rock Island plots, where the nearest other pears are about 4 miles away, were always low (1, 1, 5, 1; by year). Due to these observations, combined with the results shown in Figure 4, it is speculated that pear psylla are able to disperse readily through the scale of the Wenatchee Valley, even to relatively isolated orchards.

There were no correlations found with natural enemies, which were also highly variable between plots and years. *Campylomma* overwinter as eggs in pear orchards and other plants. *Campylomma* nymphs were found before winged adults in pear orchards each year (Figure 5), suggesting that their main population source is from within pear orchards. *Deraeocoris* overwinter as adults in pears and other plants. The main first appearance of *Deraeocoris* nymphs and adults were found around the same time in pear plots each year. If insects overwintering outside of pear orchards are moving in earlier in the spring, they are in numbers that are very low and difficult to detect. *Trechnites* are thought to be specialists of pear psylla nymphs, so again their main population source would be expected to be from within the pear orchard. Lacewings and coccinellids were found in too small numbers and sporadically for analysis.

The ultimate indicator of a pest management program's ability to control a pest is fruit damage. There was no significant correlation with landscape factors and fruit damage ratings in any year. Like with previous metrics, damage was highly variable between plots and years.

The results suggest that the Wenatchee landscape as a whole may have some effect on pest pressure, but the local landscape around specific plot has less of an effect than other factors.

Results – District comparisons. Taking together the data from all objectives, it is possible to consider associations between pear psylla pressure across districts in light of various hypotheses brought up by growers and consultants. A latitudinal gradient, with increasing pear psylla pressure at higher latitudes is not supported. British Columbia and Yakima have low pear psylla pressure, breaking the pattern between California, Southern Oregon, Hood River, and Wenatchee. Districts with higher pear psylla pressure have the highest acreages of pear (i.e., Hood River and Wenatchee are the highest-acreage districts). However, it should be considered that Sacramento Delta in California has considerable acreage, about 6,000 acres. Wenatchee and Hood River also have a higher proportion of Anjou pears relative to other districts. Wenatchee is notable for having scarce earwigs compared with all other districts with earwig monitoring data. Lastly, more intensive spray programs are correlated with higher pear psylla pressure (Figure 3B).

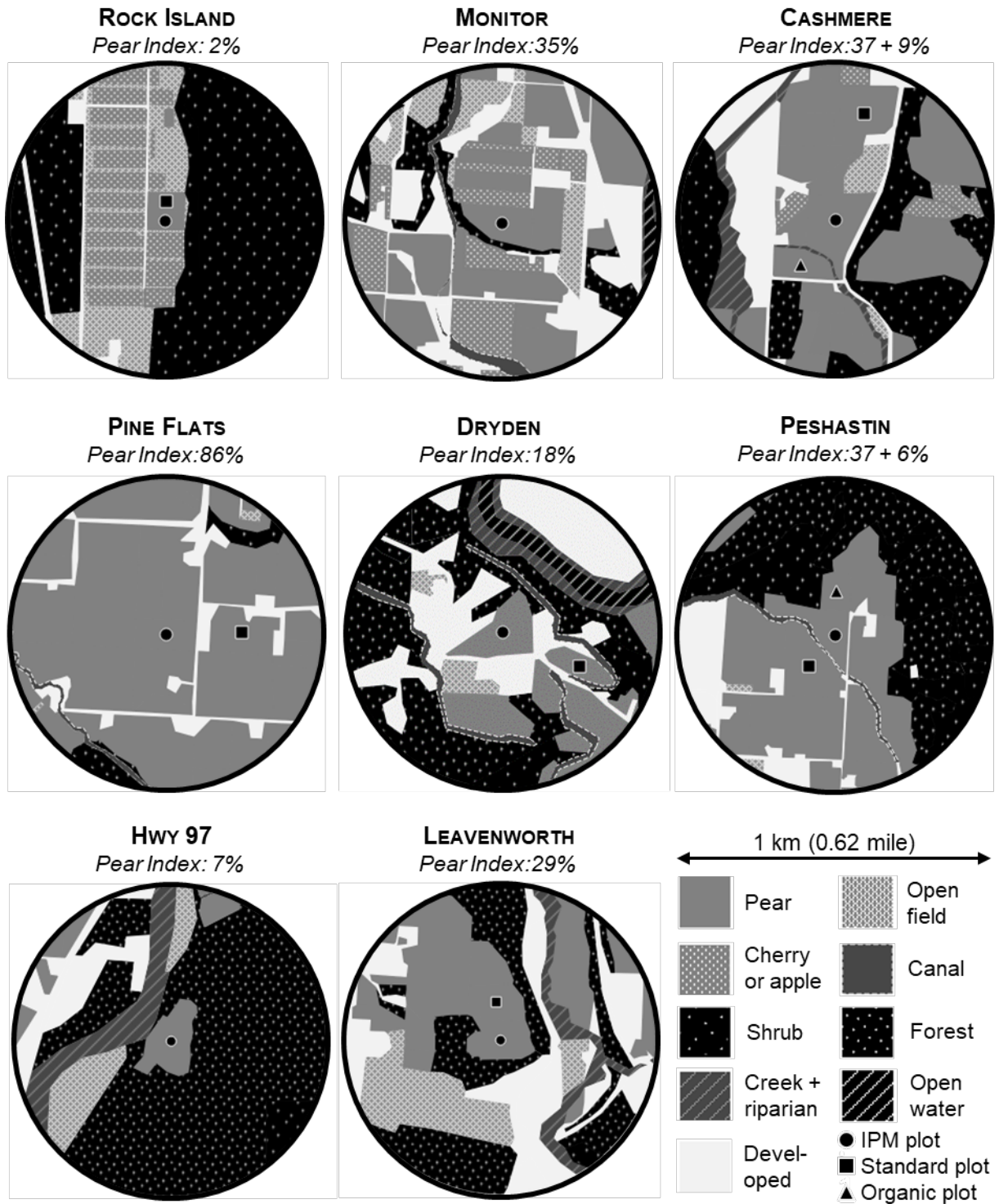


Figure 8. Visualization of pear landscapes around study plots (IPM plots only due to space limitations). The “Pear Index” is the percentage of conventional pears + organic pears within the radius of a given location.

Executive Summary

Assessing and supporting effective areawide pear pest management

Integrated pest management, landscape, pear psylla, survey

This project was designed to produce and share information that would help pear growers reduce chemical control costs while reducing damage of the key pest pear psylla by using an integrated pest management program (IPM) that conserves biocontrol. A survey was conducted and found that growers in Wenatchee used the most pesticides yet had the greatest pear psylla problem. An IPM program was designed for use in Wenatchee. It was built around a pear psylla phenology model for spray timings and a list of biocontrol-compatible spray options. The program was evaluated in commercial orchards from 2022–2025. The growers reduced spray costs in IPM plots in most years, but retained higher pesticide use than other districts through extensive applications of kaolin, azadirachtin, cinnamon oil, and other chemicals. The program resulted in similar pear psylla as standard programs. In Hood River and Yakima, growers meant to be trialing IPM programs ended up using blended programs that reduced but did not eliminate sprays excluded in the IPM guidelines, and outcomes were variable. Local and large-scale landscape factors were considered. Hood River pesticide use and pear psylla abundance was more similar to Wenatchee than we had assumed when the project was designed. Characteristics of Wenatchee and Hood River that may be associated with high pear psylla pressure relative to other districts includes high pesticide use (potential impairing biocontrol and causing pest resurgence), high pear acreage, and the Anjou cultivar. Notably, standard plots in Wenatchee generated very high overwintering pear psylla population in fall relative to IPM plots, but adult counts became similar between plots in spring. Overwintering pear psylla adults are known to be highly dispersive. It stands to reason that areawide adoption of IPM decreases pear psylla pressure across a district. An extensive program of field days, discussion groups, and newsletters shared data from the project, and adoption of IPM increased during the project. The survey and insect monitoring results here provide a conceptual basis for pear IPM and baseline data to compare with in the future.

Proposal Title: On-farm evaluation of pear psylla and natural enemy thresholds
Report Type: Continuing Report

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2025 Scouting Network participants included Wenatchee pear growers Blaine Smith, Darin Kenoyer, Dave Burnett, Dave Piper, Fred Boyd, Greg Hardnen, Julia Thacker, Dillon Miller, Randy Arnold, Glade Brosi, Jorge Zavola, Josh Hill, John Russell, Keith Archibald, Keith Goehner, Kevin Carney, Kramer Christensen, Loren Baird, Matt McDevitt, Mel Weythman, Mike Jergens, Phil Guthrie, Rollin Smith, Sam Parker, Shawn Cox, Stuart Rudolf, Todd McDevitt, Tory Schmidt, Tyler Fischer, Wayne Reiman; and consultants Chris Strohm, Northwest Wholesale; Chuck Weaver, Jake Carson, GS Long; Keith Granger, Kevin Kenoyer, Wilbur Ellis; Niel Johnson, Scott Cummings, Troy Davis, Chamberlin Agriculture; Yakima pear growers Andrew Sunquist, Yakima consultant Justin Ellgen; Hood River Growers Alex Ing, Erick VonLubken, Andy Kennedy, Jon Laraway, Jack Brennan; and consultants Ray Ishizaka, Jeff Nelson, and Torey Schmidt.

Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$19,050
Total Project Request for Year 2 Funding: \$19,813
Total Project Request for Year 3 Funding: \$20,605

Budget 1

Primary PI: Tianna DuPont
Organization Name: Washington State University
Contract Administrator: Darla Ewald | Stacy Mondy
Telephone: (509) 293-8758
Contract administrator email address: dewald@wsu.edu | arcgrants@wsu.edu

Item	2024	2025	2026
Salaries	\$14,093.00	\$14,657.00	\$15,243.00
Benefits	\$4,957.00	\$5,156.00	\$5,362.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies			
Travel			
Plot Fees			
Miscellaneous			
Total	\$19,050.00	\$19,813.00	\$20,605.00

Footnotes:

Other related/associated funding sources: Awarded

Funding Duration: 2021 – 2024

Amount: \$246,524

Agency Name: Washington State Specialty Crop Block Grant

Notes: Scouts and Thresholds: Implementing Biologically Based Pear IPM – Funding developed a scouting network.

Other related/associated funding sources: Awarded

Funding Duration: 2024

Amount: \$18,925

Agency Name: Washington State Commission on Integrated Pest Management

Notes: On-farm Evaluation of Pear Psylla and Natural Enemy Thresholds

Other related/associated funding sources: Awarded

Funding Duration: 2025-2026

Amount: \$323,134 (\$231,982 to this PI)

Agency Name: USDA NIFA Crop Protection and Pest Management

Notes: Implementing New Tools for Pear Integrated Pest Management

Objectives

- 1) Test the accuracy of natural enemy inaction thresholds: if natural enemy inaction thresholds are met do pear psylla populations remain under control.
- 2) Test the accuracy of pear psylla economic thresholds: If psylla populations are \leq ET do pest populations remain below economic injury levels (EIL)?
- 3) Test the accuracy of pear psylla population models during second and third generation.

Significant Findings

- In 2024 natural enemy inaction thresholds (*D. brevis* immatures greater than 0.2 per tray, European earwigs per trap are greater than 2, *C. verbasci* immature per beat tray are greater than 0.1 or European earwigs per beat tray are greater than 0.05) predicted no significant change in third generation young psylla nymph populations.
- In 2025 when young nymphs per leaf are below the psylla threshold of 1 per leaf and natural enemies are above natural enemy inaction thresholds, psylla young nymphs only increase in 4 of 72 cases (<6% of the time).
- One hundred percent of sites where young psylla nymphs were below the economic injury level in both the second and third generation had higher than 95% US1 in 2024.
- In 2025 85% percent of sites where young psylla nymphs were below the EIL in both the second and third generation had less than 5% psylla/mealy bug downgrades
- Psylla population prediction models which predict psylla nymph and adult numbers 200 PPDD in the future based off of current numbers, psylla phenology and natural enemy numbers performed better for nymphs and with less accuracy for adults using 2023 data than the using the data used to create the model (2017-2021).

Methods

Data analyzed for the following evaluation of thresholds was collected by leveraging scouting information collected through the ‘Scouting Network’ funded through state WSDA funds (2024) and national USDA Crop Protection funds (2025). Data collected included weekly counts of psylla adults and natural enemy adults and immatures per beat tray as well as psylla nymphs per leaf and end of season fruit quality. 2024 orchards included 87 registered scouting blocks encompassing 914 acres where 50 to 81 were scouted each week. Orchards were scouted by 6 scouts, 2 grant funded WSU scouts, 2 from chemical distributor and fruit warehouses and 2 grower scouts. 2025 orchards included 82 registered blocks encompassing 808 acres. Orchards were scouted by 6 scouts including 1 chemical distributor and 1 grower funded scout and with individual plots paid for by chemical distributors and growers.

Scouting: Scouting methods were per (DuPont *et al.*, 2023). Plots were scouted once per week from April to October using beat trays, leaf samples, and earwig traps. Within each plot, thirty samples of canopy dwelling arthropods was collected using the beat tray method. Each beat tray sample (one ‘tray’) involves holding a 45 by 45 cm white sheet 30 to 45 cm underneath a horizontal branch and striking it three times with a stiff rubber stick to dislodge insects onto the tray, which were then counted. Branches selected for sampling were 1 to 2 m above ground and 1.5 to 4 cm in diameter. The number of pear psylla adults and natural enemies per beat tray were counted. Major natural enemies included in analysis were adult *T. insidiosus*, Araneae (spiders), Anthocoridae (minute pirate bugs), *C. verbasci* (common mullein bugs), Chrysopidae (green lacewings), Coccinellidae (ladybird beetles), *D. brevis*, *Forficula auricularia* (European earwig), Geocoridae (big-eyed bugs), Hemerobiidae (brown lacewings), and Nabidae (damselfly bugs). Additionally, leaf samples were taken to determine densities of pear psylla eggs and nymphs. During the first generation 25 fruit spurs, 1 from each of 25 randomly selected trees was collected for determination of psylla eggs and nymphs (Burts and Retan, 1973; Deronzier and Atger, 1980; Beers *et al.*, 1993; California, 1999; Horton, 1999a; DuPont *et al.*, 2023). During the second generation one

hundred leaves were collected from ten randomly selected trees distributed throughout each plot (Burts, 1988; DuPont and Strohm, 2020; DuPont *et al.*, 2021; DuPont *et al.*, 2023). Lower canopy leaves were selected with two leaves from the center (representing hard to spray), 1 leaf from the middle of each of 2 leaders, and one from outer section of the scaffold 1.2 to 1.8 m from the ground. Upper canopy leaves were collected using a telescopic pruner from 2 suckers/shoots/spurs 1 on each side of the tree in areas that are difficult to spray (upper canopy/ back of limbs) (Horton, 1994; DuPont *et al.*, 2021). Collected leaves were kept cool and returned to the lab to be processed using a leaf brusher (Leedom Enterprises). Leaves were run through two motorized brushes which dislodge arthropods onto a revolving glass plate, creating a composite sample of arthropods which were counted under a stereoscopic microscope (Burts, 1988; Horton, 1999b). Arthropods collected from the leaves included pear psylla eggs, young pear psylla nymphs (instars 1-3), old pear psylla nymphs (instars 4-5), mummified pear psylla nymphs, mealybugs, European red mites, *Panonychus ulmi*; spider mites *T. urticae*, *T. mcdanieli*; and pear rust mites, *Epitimerus pyri* (Nalepa).

Fruit: Using funding from this proposal and leveraged WCIPM funds (2024), fruit data was collected. One week prior to harvest, pear fruits were inspected on 20 randomly selected trees at each site and categorized as either U.S. #1 (best), Washington (WA) Fancy (downgraded, but marketable), or Cull (unmarketable) based on USDA pear packing grades for pear psylla marking (USDA 2007). Fruit was evaluated for bartlett (34 orchard plots) and dAnjou (43 orchards) in 2024. In 2025 fruit was evaluated for dAnjou (66 orchard plots) and bartlett (31 orchard plots).

Statistics: Objective 1: To address the hypothesis that when natural enemies are above the threshold proposed by DuPont *et al.* 2023, third-generation psylla young nymphs did not significantly increase, we tested the relationship between pear psylla densities and natural enemy densities. To determine the impact of natural enemy populations thresholds, a linear regression of the population of young psylla nymphs between the beginning (PPDD = 2240) and maximum of the third-generation before harvest (PPDD = 4,100) was conducted for 2 categories where natural enemies are above or below identified thresholds. The slope of the regression was determined and if the slope was ≤ 0 was considered no increase. Additionally a Fisher exact test was conducted where the psylla young nymph number at the end of the season was compared to the number at that date where a difference of less than 0.3 was considered the same. The category “above” is designated where the average *D. brevis* immatures per beat tray for a two week period are greater than 0.2, European earwigs per trap are greater than 2, *C. verbasci* immature per beat tray are greater than 0.1 or European earwigs per beat tray are greater than 0.05. If natural enemies are not above identified thresholds, the category will be designated as “below.” The model was tested using a linear mixed model.

Objective 2: To test the association between pear psylla young nymphs ET at both 1300 and 2600 PPDD with population levels that exceed the EIL, we analyzed the data using a McNemar test. Similar to contingency tests McNemar’s test can be used to analyze categorical data but when variables are related. McNemar’s test was used to show the number of observations that fall into a combination of categories: if psylla levels \leq ET at 1300 and 2600 PPDD and psylla max for the generation did not exceed the EIL or if psylla levels \geq ET at 1300 and 2600 PPDD and psylla max for the generation did exceed the EIL. EIL designated for young nymphs was designated as 0.9 young nymphs per leaf second generation corresponding to the low yield low price scenario of 40 bins per acre and \$23.30 per box US1 and ET of 0.15 nymphs per leaf at 1300 PPDD for IPM at the associated yield and price. EIL for the third generation young nymphs was designated as 1 young nymphs per leaf second generation corresponding to the low yield low price scenario of 40 bins per acre and \$23.30 per box US1 and ET of 0.77 nymphs per leaf at 2600 PPDD for IPM at the associated yield and price. The relationship between EIL and fruit quality was assessed using a McNemar test for when psylla were below the EIL for both second and third generations and the fruit grade for insect damage at less than one week before harvest. A Phi Coefficient was used to assess the strength of associations among the variables. A Fisher exact test was used to test frequency

estimations and determine whether there is an association between the economic injury levels and end of season fruit quality.

Objective 3: To test the accuracy of pear psylla population model projections the mean average error was calculated for predicted versus actual populations using 2023 data for second and third generation nymphs and adults where mean average error (MAE) equals the sum of the absolute errors divided by the sample size $MAE = \frac{\sum|predicted-actual|}{number\ of\ data\ points}$. Young nymph generations were defined as second-generation 1015 to 2690 PPDD, and third-generation 2240 to 3600 PPDD. Adults first-generation were 50 to 790 PPDD, second-generation 895 to 2315 PPDD, third-generation 2305 to 3600 PPDD. PPDD per generation were designated from where 10 to 90% cumulative proportion of the generation was predicted to occur (Jones et al. 2020). Confidence intervals (CI) were determined based on the MAE where $CI\ (90\%) = MAE + \frac{\sigma}{\sqrt{n}} \times 1.64$.

Results and Discussion

Objective 1. Natural enemy inaction threshold validation. The relationship between natural key natural enemies at the beginning of the third generation and the maximum number of psylla nymphs of the third generation was analyzed using linear regression.

In 2024 when the average number of natural enemies for two weeks early third generation was above the natural enemy threshold (*D. brevis* immatures per beat tray greater than 0.2, European earwigs per trap are greater than 2, *C. verbasci* immature per beat tray greater than 0.1 or European earwigs per beat tray are greater than 0.05) the number of young psylla nymphs per leaf did not increase (no significant change; $p=0.0948$) but where the number of natural enemies was below the threshold psylla young nymph numbers had a significant increase (0.0253). This analysis supports the published model where when natural enemies are above thresholds psylla populations tend not to increase.

In 2025 when the average number of natural enemies for two weeks early third generation was above the natural enemy threshold the number of young psylla nymphs per leaf did increase ($p<0.0001$; $R^2\ 0.32$; 34 observations) and where the number of natural enemies was below the threshold psylla numbers also significantly increased ($p<0.0001$; $R^2\ 0.33$; 38 observations). When natural enemy numbers were above the thresholds, young psylla numbers increased in 22 of 34 cases (65% of the time) and had no increase in 12 of 34 cases (34% of the time). When natural enemy numbers were below thresholds, young psylla nymphs increased in 34 of 38 cases (89% of the time) and had no increase in 4 of 38 cases (11% of the time). However, if the dataset is limited to where young nymphs per leaf are below the psylla threshold of 1 per leaf for plots, where natural enemies are above the threshold psylla young nymphs only increase in 4 of 72 cases (<6% of the time) which is not significant using Fisher's exact test $p=0.5$. This re-emphasizes that the natural enemy and psylla thresholds have to be used together where only when natural enemies are above the threshold and psylla are below economic thresholds can we rely on natural enemies to keep psylla in check. At higher levels, while natural enemy numbers may be high they are tracking high psylla populations rather than indicating pest suppression.

Objective 2. Pear psylla ET and EIL validation. A McNemar's test was used to determine the number of observations that fall into a combination of categories: if psylla levels are \leq ET at 1300 and 2600 PPDD and did not exceed the EIL or if psylla levels \geq ET at 1300 and 2600 PPDD and exceed the EIL. A Fisher exact test was used to test frequency estimations and determine whether there is an association between the economic injury levels and end of season fruit quality.

Analysis of 2024 data showed that 27% of the time when psylla young nymphs were below the economic threshold at the beginning of the second generation, maximum numbers of young psylla nymphs in the second generation exceeded the injury level (Table 1). For the third generation, when young psylla nymphs were below the economic threshold at the beginning of the generation, maximum populations exceeded the economic injury level only 10% of the time (Table 2). This relationship was significant for the second and third generation ($p < 0.0001$).

Analysis of 2025 data showed that 0% of the time when psylla young nymphs were below the economic threshold at the beginning of the second generation, maximum numbers of young psylla nymphs in the second generation exceeded the injury level (Table 3; $N=71$). For the third generation, when young psylla nymphs were below the economic threshold at the beginning of the generation, maximum populations exceeded the economic injury level only 14% of the time (Table 4; $N=73$). This relationship was significant for the second and third generation ($p < 0.0001$; 0.0164).

As the ET at the beginning of the generation did not predict with 100% accuracy that psylla numbers will not exceed economic injury levels it is recommended that users sequentially assess populations on a weekly basis where managers can consider that if their pest pressure is below thresholds this week a spray can be delayed and reconsidered the following week.

Table 1. McNemar contingency table showing proportion of plots which were above or below the economic threshold (ET) at 1300 PPDD to proportion of plots above or below economic injury level (EIL) during second generation in 2024. $N=71$. $p < 0.0001$. EIL defined for 40 bins per acre and US1 at \$23.3 per box for IPM system.

	ABOVE EIL >0.9 psylla young nymphs max second generation	BELOW EIL < 0.9 psylla young nymphs max second generation
ABOVE ET >0.15 psylla young nymphs per leaf at 1300 PPDD	77% (27 of 35)	23% (8 of 35)
BELOW ET <0.15 psylla young nymphs per leaf at 1300 PPDD	27% (10 of 36)	72% (26 of 36)

* Note reported as proportion in scenario represented in a row. In 2024 reported as proportion of all plots.

Table 2. Contingency table showing proportion of plots which were above or below the economic threshold (ET) at 2600 PPDD to proportion of plots above or below EIL at maximum during third generation in 2024 (by row). $N=75$. $p < 0.0001$ Fisher Exact test. EIL defined for 40 bins per acre and US1 at \$23.3 per box for IPM system.

	ABOVE EIL >1 psylla young nymphs max third generation	BELOW EIL < 1 psylla young nymphs max third generation
ABOVE ET >0.77 psylla young nymphs per leaf at 2600 PPDD	80% (20 of 25)	20% (5 of 25)
BELOW ET <0.77 psylla young nymphs per leaf at 2600 PPDD	10% (5 of 50)	90% (45 of 50)

* Note reported as proportion in scenario represented in a row. In 2024 reported as proportion of all plots.

Table 3. **2025 data.** McNemar contingency table showing proportion of plots which were above or below the economic threshold (ET) at 1300 PPDD to proportion of plots above or below economic injury level (EIL) during second generation in 2025. N=71. McNemar Chi Sq. $p = 0.0047$. Fisher Exact test $p = <.0001$. EIL defined for 40 bins per acre and US1 at \$23.3 per box for IPM system.

	ABOVE EIL >0.9 psylla young nymphs max second generation	BELOW EIL < 0.9 psylla young nymphs max second generation
ABOVE ET >0.15 psylla young nymphs per leaf at 1300 PPDD	43% (6 of 14)	57% (8 of 14)
BELOW ET <0.15 psylla young nymphs per leaf at 1300 PPDD	0% (0 of 57)	100% (57 of 57)

Table 4. McNemar contingency table showing proportion of plots which were above or below the economic threshold (ET) at 2600 PPDD to proportion of plots above or below EIL at maximum during third generation in **2025**. N=73. McNemar Chi Sq. $p = 0.0067$. Fisher Exact test $p = 0.0164$. EIL defined for 40 bins per acre and US1 at \$23.3 per box for IPM system.

	ABOVE EIL >1 psylla young nymphs max third generation	BELOW EIL < 1 psylla young nymphs max third generation
ABOVE ET >0.77 psylla young nymphs per leaf at 2600 PPDD	75% (3 of 4)	25% (1 of 4)
BELOW ET <0.77 psylla young nymphs per leaf at 2600 PPDD	14% (10 of 69)	86% (59 of 69)

In 2024 Of 43 orchards evaluated for end of season fruit marking from insect damage on ‘dAnjou fruit, 23 of those sites did not have honeydew washing and could be used to look at the relationship between psylla numbers and final fruit grade (regarding insect damage). One hundred percent of sites where young psylla nymphs were below the EIL in both the second and third generation had higher than 95% US1 (Table 5). In 30% of cases the EIL was exceeded in either the second or third generation and fruit grade still exceeded 95% US1 (Table 5). This may be due to a drenching rain on August 23, 2024 (0.61 in) nicely timed to wash honeydew from fruit and prevent fruit marking. Overall, this relationship between combined EIL and insect related fruit downgrades was significant ($p<0.001$) with a strong relationship (Phi Coefficient 0.84).

In 2025 of 65 orchards evaluated for end of season fruit marking from insect damage on ‘dAnjou fruit, 36 of those sites did not have honeydew washing and could be used to look at the relationship between psylla numbers and insect downgrades due to psylla and mealybug. 85% percent of sites where young psylla nymphs were below the EIL in both the second and third generation had less than 5% psylla/mealy bug downgrades (Table 7). In 4% of cases (1 orchard) the EIL was exceeded in either the second or third generation and fruit grade still had less than 5% psylla/mealy bug downgrades (Table 7). Overall the relationship between combined EIL and insect related fruit downgrades had a strong relationship where no honeydew washing occurred (Phi Coefficient 0.91). With honeydew washing 29% of cases where EIL

was exceeded in either the second or third generation had less than 5% psylla/ mealy bug downgrades (Table 6).

Table 5. Number of sites in 2024 with maximum psylla nymphs above or below the EIL for both the second and third generation compared to the percentage of US1. Rating performed on 200 fruit per block in the field using USDA grading standards for insect damage. Sites without honeydew washing included. N=23. Fisher test p<0.0001.

% psylla downgrades			Above EIL	Below EIL
			frequency	
>20%			6	0
19	to	15	2	0
15	to	10%	2	0
9.9	to	7.5	1	0
7.4	to	5	1	1
4.9	to	2.5	0	2
2.4	to	0	5	3

Table 6. Number of sites in 2025 with maximum psylla nymphs above or below the EIL for both the second and third generation compared to the percentage of US1. Rating performed on 200 fruit per block in the field using USDA grading standards for insect damage. Sites with and without honeydew washing included. N=46.

% psylla downgrades			Above EIL	Below EIL	Total	aboveEIL	belowEIL
			frequency			percent	
>20			1	0	1	100	0
19	to	15	---	---	---	---	---
14.9	to	10	6	1	7	86	14
9.9	to	7.5	2	1	3	67	33
7.4	to	5	1	4	5	20	80
4.9	to	2.5	3	12	14	20	80
2.4	to	0	1	17	18	6	94

Table 7. Number of sites in 2025 with maximum psylla nymphs above or below the EIL for both the second and third generation compared to the percentage of US1. Rating performed on 200 fruit per block in the field using USDA grading standards for insect damage. Sites without honeydew washing included. N=36.

% psylla downgrades			aboveEIL	belowEIL	Total	aboveEIL	belowEIL
			frequency			percent	
>20%			1	0	1	100	0
19	to	15					
14.9	to	10%	4	1	5	80	20

9.9	to	7.5	2	1	3	67	33
7.4	to	5	0	4	4	0	100
4.9	to	2.5	1	8	9	11	89
2.4	to	0	0	14	14	0	100

Objective 3. The psylla population models are used to create predictions of where psylla numbers may be next week based on current scouting data for both psylla and natural enemies. These numbers can then be compared to economic thresholds to help growers make decisions. For example if current and projected psylla numbers are below the threshold and natural enemies are above the threshold a grower may decide to delay a spray, waiting to re-evaluate the following week.

By comparing psylla numbers projected by the model to the actual number that was recorded the following week we can calculate the mean absolute error (MAE) and compare those values to the MAE of the published model. Using 2023 data the MAE for second generation nymphs was 0.2 and for third generation was 0.22 (Table 8). The MAE for second generation adults was 1.01 and for third generation adults was 1.53. In comparison in the published model the comparison of the modeled population compared to the predicted population one week in the future (time between pest population measured and intervention likely to occur) had a mean absolute error of 0.33 (second-generation psylla young nymphs), 0.98 (third-generation psylla young nymphs), 0.10 (second-generation psylla adults), and 0.15 (third-generation psylla adults).

As such the model for predictions performed better on 2023 data than in the original model for nymphs but not as well for adults. The large MAE for adults in 2023 stem from plots that had high numbers of psylla adults and so the sensitivity may be better for the lower numbers.

Confidence intervals calculated from the MAE are helpful to illustrate how we can use this information. For example if an orchardist receives a report like that in figure 2 where the predicted young psylla nymph number for the upcoming week (200 PPDD in the future) is 0.1 at a 90% confidence interval of 0.27 the individual could be 90% confident that the number would not exceed 0.37 young psylla nymphs per leaf the following week.

Table 8. Mean average error (MAE) for psylla population predictions.

	MAE published model	MAE 2023	90% CI	95% CI
young nymphs gen 2	0.33	0.2	0.25	0.26
young nymphs gen 3	0.98	0.22	0.27	0.28
adults gen 2	0.10	1.0	1.28	1.33
adults gen 3	0.15	1.5	1.89	1.97

Significance to the industry.

Thresholds and scouting add additional tools to the integrated pest management toolbox designed to improve pest management, reduce costs and improve fruit quality. Integrated pest management programs generally include particle films, oils and insect growth regulators early in the season followed by selective insecticides targeted to young nymphs (Figure 1). During the latter part of the second and third generation orchards can use scouting data to determine if psylla numbers are below inaction thresholds (Figure 2) and natural enemy numbers are above thresholds (Figure 3) and then with greater confidence determine if they can delay sprays or reduce the number of materials in an upcoming spray. Testing of both psylla and natural enemy thresholds is critical to determine at what level of confidence these thresholds can be used as a guide.

Extension

Pear Pest Management Discussion group meetings were held: March 21, 2025 (48 participants), April 20, 2025 (22 participants), May 5, 2025 (16 participants), June 12, 2025 (15 participants), and October 8, 2025 (32 participants). A Pear IPM Field Day was held July 10, 2025 (64 participants). Weekly scout trainings were conducted April-Aug for 6 scouts.

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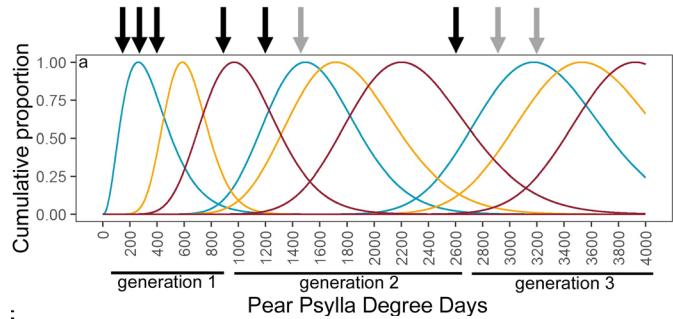
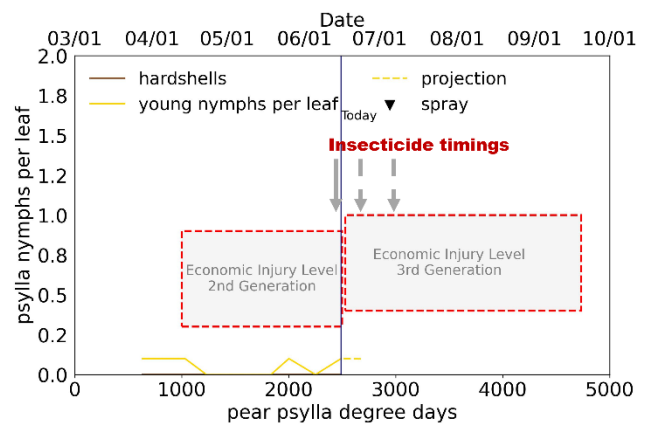
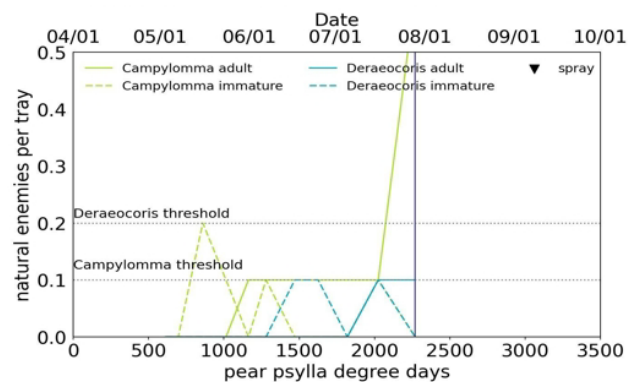


Figure 1. Pear psylla phenology model. Black arrows indicate recommended timings for spray applications. Grey arrows indicate optional timings where sprays should be applied if psylla numbers are high. Figure generated by R. Orpet.



EIL = Economic Injury Level 5% culls at 0.4 to 1 young nymph per leaf depending on price and yield. ET at 2600 for 2600 to 3200
PPDD sprays = 0.2 to 0.8 nymphs per leaf to avoid max population above EIL.

Figure 2. Example of scouting data received and how it can be used to compare to inaction thresholds. The panel shows data for young psylla nymphs per leaf (yellow line) and projected young psylla nymphs per leaf (yellow dashed line) compared to the range of the economic injury level.



When Deraeocoris immatures exceeded 6 per 30 trays (0.2 avg) or Campylomma immatures exceeded 3 per 30 trays (0.1 avg) psylla populations tend not to increase in the third generation.

Figure 3. Example scouting data showing *Campylomma* (green line) and *Deraeocoris* adult and immature data (blue lines) compared to thresholds at which psylla populations tend not to increase in the third generation.

DuPont, S.T., Strohm, C., Kogan, C., Hilton, R., Nottingham, L., Orpet, R., 2023. Pear psylla and natural enemy thresholds for successful integrated pest management in pears. *Journal of Economic Entomology*.

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Proposal Title: Can Scouting and Thresholds Increase Pear IPM Adoption and Improve Fruit Quality

Report Type: New Proposal

Primary PI: Tianna DuPont
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Cooperators: 2025 Scouting Network participants included Wenatchee pear growers Blaine Smith, Darin Kenoyer, Dave Burnett, Dave Piper, Fred Boyd, Greg Hardnen, Julia Thacker, Dillon Miller, Randy Arnold, Glade Brosi, Jorge Zavola, Josh Hill, John Russell, Keith Archibald, Keith Goehner, Kevin Carney, Kramer Christensen, Loren Baird, Matt McDevitt, Mel Weythman, Mike Jergens, Phil Guthrie, Rollin Smith, Sam Parker, Shawn Cox, Stuart Rudolf, Todd McDevitt, Tory Schmidt, Tyler Fischer, Wayne Reiman; and consultants Chris Strohm, Northwest Wholesale; Chuck Weaver, Jake Carson, GS Long; Keith Granger, Kevin Kenoyer, Wilbur Ellis; Niel Johnson, Scott Cummings, Troy Davis, Chamberlin Agriculture; Yakima pear growers Andrew Sunquist, Yakima consultant Justin Ellgen; Hood River Growers Alex Ing, Erick VonLubken, Andy Kennedy, Jon Laraway, Jack Brennan; and consultants Ray Ishizaka, Jeff Nelson, and Torey Schmidt.

Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$25,427

Total Project Request for Year 2 Funding: \$26,190

Total Project Request for Year 3 Funding: \$26,982

Other related/associated funding sources: Awarded

Funding Duration: 2021 – 2024

Amount: \$246,524

Agency Name: Washington State Specialty Crop Block Grant

Notes: Scouts and Thresholds: Implementing Biologically Based Pear IPM – Funding developed the Scouting Network including mobile application.

Other related/associated funding sources: Awarded

Funding Duration: 2024

Amount: \$18,925

Agency Name: Washington State Commission on Integrated Pest Management

Notes: On-farm Evaluation of Pear Psylla and Natural Enemy Thresholds

Other related/associated funding sources: Awarded

Funding Duration: 2024-2027

Amount: \$323,134

Agency Name: USDA Crop Protection

Notes: Implementing New Tools for Pear Integrated Pest Management

Budget 1

Primary PI:

Organization Name: Washington State University

Contract Administrator: Kevin Rimes

Telephone: (509) 293-8802

Contract administrator email address: kevin.rimes@wsu.edu

Item	2025	2026	2027
Salaries	14093 ^a	\$14,657.00	\$15,243.00
Benefits	4957 ^b	\$5,156.00	\$5,362.00
Wages			
Benefits			
RCA Room Rental			
Shipping			
Supplies	\$3,000.00	\$3,000.00	\$3,000.00
Travel	3377 ^c	\$3,377.00	\$3,377.00
Plot Fees			
Miscellaneous			
Total	\$3,000.00	\$26,190.00	\$26,982.00

Footnotes: ^a 3 months per year Post doc or scientific assistant salary to evaluate scouting network including survey instrument design/review (1 week/yr), survey interviews (4 weeks/yr), survey summarization, analysis and reporting (2 weeks per year, fruit evaluations (4 weeks/yr), spray trials (3 weeks/yr). ^bBenefits rate 35.2%. ^cTravel at \$0.70/mi, 4,824 miles.

Objectives

Objective 1: Evaluate the impacts of scouting on pear operations. Scouting Network participants (40 est.) will be surveyed to document the impacts of scouting on spray timings, number of applications, use of thresholds, numbers of broad spectrum applications, adoption of IPM programs using selective products, reduction in costs and improvements in fruit quality. We anticipate 1500 acres will use scouting information to inform spray decisions and as a result growers will see reduced costs associated with spray applications, improved fruit quality and increased adoption of IPM.

Objective 2: Evaluate the impact of scouting on pear fruit quality. We will conduct fruit quality evaluations on a subset of 50 pear orchards where orchardists received weekly scouting reports. Less than one week prior to harvest, pear fruits will be inspected on 20 randomly selected trees at each site and categorized as either U.S. #1, Washington (WA) Fancy, or Cull based on USDA pear packing grades for pear psylla marking (USDA 2007). Insect fruit damage in scouted blocks will be compared to target levels of less than 5% downgrades and to US1 for the average of the top of the pool at each warehouse.

Objective 3: Evaluate the impact of scouting on spray costs. Scouting allows growers and consultants to compare pest and natural enemy populations to threshold levels. When natural enemies are high and pest numbers are low spray applications can be avoided or the number of materials in the spray tank can be reduced. In order to determine the impact of scouting information on spray costs pesticide records will be analyzed for a subset of 25 orchard blocks per year. Based on spray records number of applications, number of materials and costs will be tabulated and compared to average use in the same block the previous 2 years.

Objective 4: Evaluate the ability of Scouting Networks to help us refine pear IPM programs. While the primary goal of Scouting Networks is to help orchardists apply research-based information to improve their pest management, the network approach can also be leveraged to answer emerging questions. For example, using this approach data was collected from 50 to 81 blocks per week in 2024 versus only 21 per year using traditional research approaches. We will leverage network scouting to test revisions to IPM programs for example: does inclusion of 1 broad spectrum material pre-bloom improve IPM outcomes. Tests will be conducted by using 4 orchards as replicates for each of 2 treatments (8 total) with Scouting Network pest and natural enemy data collection.

Significant Findings

- 91% of growers and 100% of consultants reported using scouting network information to inform spray decisions. They said that using scouting information reduced spray applications and use of broad spectrum insecticide applications. 64% of growers and 63% of consultants reported using information to implement selective programs to maintain biological control impacting more than 3500 acres.
- Insect downgrades were not significantly different between IPM and top of pool blocks using either commercial or USDA scales. However, the average number of downgrades in Scouted IPM blocks was higher than the 5% or less target.

Results and Discussion

Objective 1: Evaluate the impacts of scouting on pear operations.

In 2025 there were 82 registered blocks, from 33 orchard operations totaling 808 acres participating in the scouting network. Orchards were scouted by 6 scouts including, USDA grant funded scouts, 1 chemical distributor and 1 grower funded scout and with individual plots paid for by chemical distributors and growers. 53 orchardists and consultants participated in the project (13 consultants, 33 orchard operations). At the end of the year participants were surveyed through interviews and online surveys. 22 orchardists managing 2866 acres of pears and 8 consultants providing recommendations for 7269 acres of pears participated in the end of year survey as of December 29, 2025.

87% of orchardists and consultants participants reported making changes to their pest management programs as a result of the project.

Growers reported using scouting network information to inform their spray decisions (91%, 1671 acres). They said they:

- adjusted spray timings based on scouting data (68%, 1527 acres),
- omitted 1+ sprays (86%, 1714 acres),
- reduced 2 to 3 late season sprays (64%, 1673 acres),
- used psylla thresholds (73%, 1464 acres),
- used natural enemy thresholds (77%, 1528 acres),
- reduced the number of broad-spectrum insecticides used (77%, 1724 acres),
- and used selective programs to maintain biocontrol (soft, IPM) (64%, 1585 acres).

As a result of these changes orchardist reported the scouting network:

- facilitated the adoption of integrated pest management (IPM) practices (55%),
- significantly improved timing and effectiveness of pest control applications (41%),
- helped identify and manage secondary pests that were previously overlooked (18%),
- reduced overall pesticide usage due to more informed and timely interventions (55%),
- significantly reduced pesticide expenses while effectively managing insects (36%),
- moderately reduced pesticide usage and costs (68%),
- increased natural enemies on the farm (55%),
- improved fruit quality (41%)

Additionally, consultants reported using scouting network information to

- inform spray decisions (100%, 5040 acres),
- adjust spray timings (88 %, 4920 acres),
- omit 1+ sprays (100%, 3920 acres),
- reduce 2 to 3 late season sprays (38%, 1295 acres),
- reduce number of broad spectrum insecticide applications (63%, 3195 acres),
- recommend selective IPM programs (63%, 3525 acres).

100% of participants are likely to recommend the Scouting Network to other growers. 9 of 22 orchardists surveyed said they would pay more than \$67 per acre for the service.

Objective 2: Evaluate the impact of scouting on pear fruit quality.

2025 orchards scouted included 82 registered blocks encompassing 808 acres. Orchards were scouted by 6 scouts including 1 chemical distributor and 1 grower funded scout and with individual plots paid for by chemical distributors and growers.

Insect data analyzed was collected by leveraging scouting information collected through the 'Scouting Network' funded through federal USDA Crop Protection Funds. Data collected included weekly counts of psylla adults and natural enemy adults and immatures per beat tray as well as psylla nymphs per leaf and end of season fruit quality.

Insect downgrades to dAnjou fruit in fifty-three scouted integrated pest management blocks (IPM) were compared to a selection of eight blocks identified as generally top of the pool by packing houses in 2025. IPM is defined here as use of no more than two broad spectrum insecticide per season (prebloom) with reliance on conservation biological control and use of scouting, thresholds, phenology based timings, and cultural controls (grower reported). In general insect downgrades were not significantly different between IPM and top of pool blocks using either commercial or USDA scales (Table 1). However, the average number of downgrades was higher than the 5% or less target. There was notable rust mite pressure in 2025 contributing to insect downgrades. However, even when considering psylla alone the number of downgrades was notably (but not significantly) higher on average in IPM than top of pool blocks when the more stringent commercial scale was used.

Honeydew washing systems can be an important component of integrated pest management programs that rely on conservation biological control in which natural enemy numbers can be variable season to season. In IPM orchards with honeydew washing systems (Table 2) the number of dAnjou culls due to psylla (or mealy bug) was quite low at 1% USDA and 1.3% commercial scale and not significantly different than 2.2% in top of pool blocks. Using the USDA grading scale scouted IPM orchards with honeydew washing met the less than 5% insect downgrades goal (4.9% IPM vs 5.5% top of pool blocks). However, with the commercial rating scale insect downgrades were 10.2% in scouted IPM blocks with honeydew washing (not significantly different than 7.2% in top of pool blocks).

It is important to consider not only the averages but the range of the data. In 2025 while many of the orchards utilizing scouting and IPM had low numbers of downgrades there was a wide variation with 8 orchards, of those with fruit rating, experiencing particularly high levels of downgrades (Figure 1). While honeydew washing reduced this variation some orchard blocks still had noticeable psylla downgrades to fancy even with washing suggesting that over-reliance on washing is a potential risk (Figure 2).

Table 1. dAnjou insect downgrades in 53 scouted IPM orchards compared to 8 orchards which packing houses identified as generally top of the pool in 2025. Insect damage was rated in the field for ten fruit per tree from twenty trees, 200 fruit total using USDA and Commercial rating scales.

	Scouted IPM	Top of Pool	p
downgrades insect (commercial)	13.4 ± 1.7	7.2 ± 3.2	0.3724
downgrades insect (USDA)	7.8 ± 1.4	5.6 ± 2.9	0.7369
downgrades psylla (commercial)	11.1 ± 1.4	7.2 ± 3.2	0.1915
downgrades psylla (USDA)	5.5 ± 0.9	5.5 ± 2.9	0.7469
Fancy insect downgrade (commercial)	10.5 ± 1.2	5.0 ± 2.2	0.0146
Third grade insect downgrade (commercial)	2.9 ± 0.8	2.2 ± 1.1	0.7080
Fancy insect downgrade (USDA)	5.0 ± 0.7	3.3 ± 1.8	0.1376
Third grade insect downgrade (USDA)	2.8 ± 0.7	2.2 ± 1.1	0.7547
Fancy psylla downgrade (commercial)	9.4 ± 1.2	5.0 ± 2.2	0.0138
Third grade psylla downgrade (commercial)	1.7 ± 0.3	2.2 ± 1.1	0.8642
Fancy psylla downgrade (USDA)	4.0 ± 0.6	3.3 ± 1.8	0.1140
Third grade psylla downgrade (USDA)	1.5 ± 0.3	2.2 ± 1.1	0.7402

Table 2. dAnjou insect downgrades in scouted IPM orchards with honeydew washing (N=14) compared to eight orchards which packing houses identified as generally top of the pool in 2025. Insect damage was rated in the field for ten fruit per tree from twenty trees using USDA and Commercial rating scales.

	Scouted IPM with honeydew washing	Top of Pool	p
downgrades insect (commercial)	10.4 ± 2.2	7.2 ± 3.2	0.1836
downgrades insect (USDA)	4.9 ± 1.2	5.6 ± 2.9	0.4463
downgrades psylla (commercial)	9.6 ± 2.1	7.2 ± 3.2	0.1932
downgrades psylla (USDA)	3.8 ± 1	5.5 ± 2.9	0.3034
Fancy insect downgrade (commercial)	8.8 ± 1.9	5.0 ± 2.2	0.1502
Third grade insect downgrade (commercial)	1.6 ± 0.4	2.2 ± 1.1	0.6169
Fancy insect downgrade (USDA)	3.5 ± 1.0	3.3 ± 1.8	0.419
Third grade insect downgrade (USDA)	1.4 ± 0.3	2.2 ± 1.1	0.5945
Fancy psylla downgrade (commercial)	8.3 ± 1.9	5.0 ± 2.2	0.1712
Third grade psylla downgrade (commercial)	1.3 ± 0.3	2.2 ± 1.1	0.4422
Fancy psylla downgrade (USDA)	2.7 ± 0.9	3.3 ± 1.8	0.3705
Third grade psylla downgrade (USDA)	1.0 ± 0.2	2.2 ± 1.1	0.4471

Figure 1. Scouted IPM orchard blocks (N=53) and packing house top of the pool blocks (N=8) rated using a commercial rating scale for fruit insect marking downgrades. dAnjou pear. Not significantly different $p=0.37$. Average of 13.4 (IPM) vs 7.2% (Top).

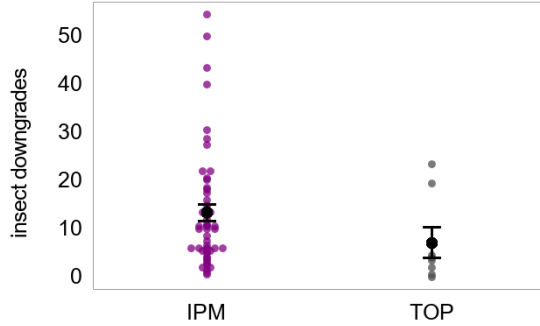


Figure 2. Scouted IPM blocks with honeydew washing and packing house top of pool blocks rated using 2025 commercial rating scale for insect fruit marking downgrades. dAnjou pear. Not significantly different $p=0.19$. Average of 9.6 (IPM) vs 7.2% (Top).

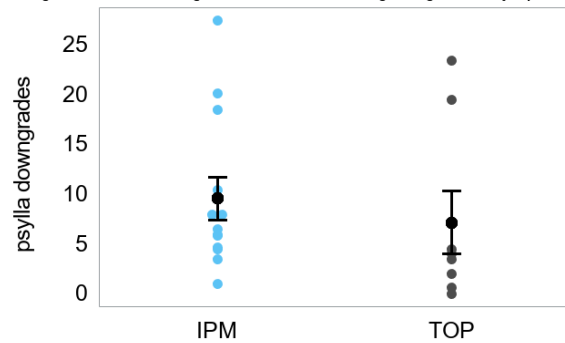


Figure 3. Scouted IPM orchards and packing house top of pool orchards rated using the 2025 commercial rating scale for insect fruit marking downgrades to cull. dAnjou pear. $p=0.7$

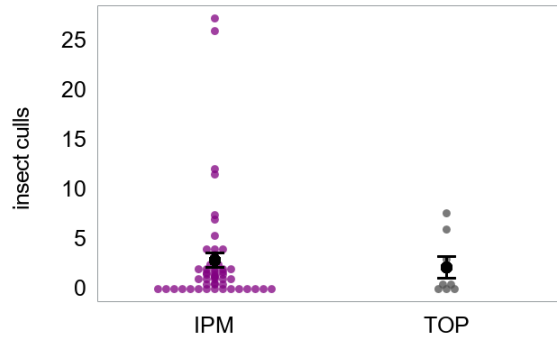


Figure 4. Scouted IPM orchards and packing house top of pool orchards rated for insect fruit marking downgrades to cull. dAnjou pear. $p=0.19$. Average of 2.9 (IPM) vs 2.2% (Top).

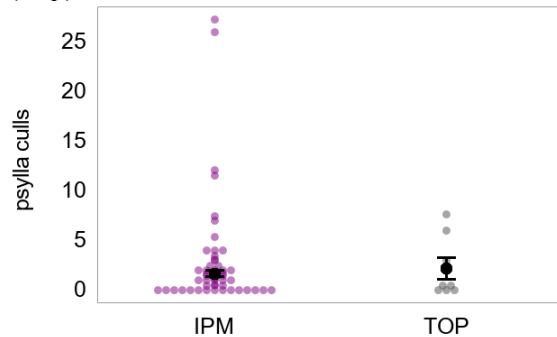
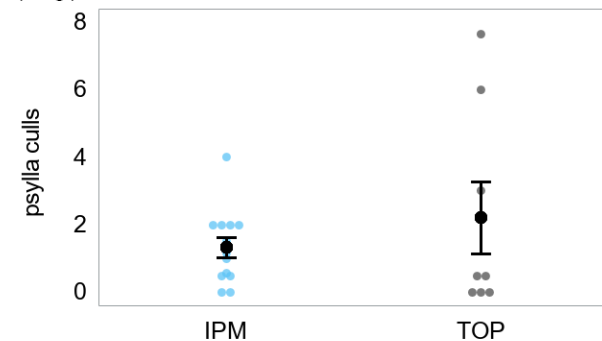


Figure 5. Scouted IPM orchards with honeydew washing and packing house top of pool orchards rated for insect fruit marking downgrades to cull. dAnjou pear. $p=0.6$ Average of 1.6 (IPM) vs 2.2% (Top).



Methods

Objective 1: Evaluate the impacts of scouting on pear operations. Thirty Scouting Network participants were surveyed to document the impacts of scouting on spray timings, number of applications, use of thresholds, numbers of broad-spectrum applications, adoption of IPM programs using selective products, and reduction in costs and improvements in fruit quality. *Participant selection:* All participants in the Scouting Network received the survey via interview or survey instrument. *Survey methodology:* Interviews were done using the interactive semi-structured interview methodology using a topic guide approach (Knott *et al.*, 2022) similar to Rapid Rural Appraisal (Kanno, 2019).

Objective 2: Evaluate the impact of scouting on pear fruit quality. Fruit quality was evaluated using a standard methodology in the field (below). Insect fruit damage in scouted blocks was compared to target levels of less than 5% downgrades. It will also be compared to blocks which are consistently in the top of the pool. A group of eight to nine total top of the pool blocks (several from each warehouse) were identified.

We conducted fruit quality evaluations on a subset of pear orchards where orchardists received weekly scouting reports. Approximately one week prior to harvest, pear fruits were inspected on 20 randomly selected trees at each site and categorized as either U.S. #1, Washington (WA) Fancy, or Cull based USDA (Table 3) and on commercial (Table 4) pear packing grades. Commercial packing grades were adapted from USDA pear packing grades for pear psylla marking (USDA 2007) using metrics from 2 commercial warehouses. Sampling was conducted where 10 fruits are inspected per tree on 20 randomly selected d’Anjou pear trees at each site. 2 to 4 fruits will be inspected per leader (1-2 fruits being on the periphery of the canopy, and the other 1-2 fruits being in the inner canopy). To capture the variation in the block inspectors will walk a ‘U’ and/or ‘Z’ pattern near trap transects and avoid sampling many trees from the same row.

Table 3. USDA pear packing grading standards for pear psylla. % refers to the amount of fruit surface with honeydew marking. Inches refer to the diameter size of the mark.

Psylla Marking	US#1	WA Fancy	3 rd Grade/Cull
Thin	< 25%	< 50%	> 50%
Moderate	< 3/4"	< 1-1/4"	> 1 1/4"
Heavy	< 1/2"	< 3/4"	> 3/4"

Table 4. Commercial pear packing grading standards for pear psylla 2025. % refers to the amount of fruit surface with honeydew marking. Inches refer to the diameter size of the mark.

Psylla Marking	US#1	WA Fancy	3 rd Grade/Cull
Thin	< 1/2"	< 25%	> 25%
Moderate	< 3/8"	< 1-1/4"	> 1 1/4"
Heavy	0	< 3/4"	> 3/4"

Objective 3: Evaluate the impact of scouting on spray costs. Increase or reduction in spray costs will be compared to the cost of scouting. In order to determine the impact of scouting information on spray costs, pesticide records were analyzed for a subset of orchard blocks each year. In 2025 records were collected and tabulated from 54 plots. Based on spray records, number of applications, number of materials, and costs will be tabulated and compared to the average used in the same block the previous 2 years. *Spray record collection:* Spray records were collected from participating orchards between October and December of each year. Each record was coded with an anonymous unique identifier (eg plot 40). *Spray record collation:* Each record was entered in

standardized format including: date, gallons per acre, product, form, rate, category (insecticide, nutrient, miticide etc), active ingredient. To ensure uniform naming a product list and look up table is used. Records are entered where each product occupies 1 line such that numbers of materials, numbers of materials in different categories as well as numbers of applications may be collated. *Spray cost designation:* Product prices were identified by communication with multiple chemical suppliers where the average of three sources is used and individual supplier prices are not public. The cost of spray application was included based on enterprise budgets Gallardo et al. 2022. *Analysis:* Analysis is ongoing.

Objective 4: Evaluate the ability of Scouting Networks to help us refine pear IPM programs. Objective 4 will be initiated in 2026 as project funding initiated in July of the current year.

Project Title: The Next Fruit 4.0

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Cooperators: Manoj Karkee and Lav Khot (Washington State University), Joseph Davidson (Oregon University)

Project size

Amount: 3,156k€ for 4 years
Agency Name: Dutch Ministry of Agriculture, Nature and Food Quality
Notes: Total project size is 3,156k€ for 4 years, half is paid by the Dutch Ministry of Agriculture, Nature and Food Quality and the other half (1,578k€) is financed by Dutch growers and companies (in cash/in kind) and the Washington Tree Fruit Research Commission. The part that is financed by WTFRC is stated below.

Item	2021	2022	2023	2024-mid 2025
Salaries	\$54,000	\$54,000	\$54,000	\$54,000
Benefits				
Wages				
Benefits				
Equipment	\$5,000	\$5,000	\$5,000	\$5,000
Supplies				
Travel				
Miscellaneous				
Plot Fees				
Total	\$59,000	\$59,000	\$59,000	\$59,000

Executive Summary The Next Fruit 4.0

The object is to make fruit cultivation more efficient, intelligent, sustainable, and future-proof. A crucial step is to be able to monitor, manage, and to act at the level of individual trees with the help of smart technology. The **first example** is the development of a precision sprayer that can spray at a nozzle level with sensors that detect the volume of the trees. Two prototypes were build and one is commercially available for growers. A later add-on are RGB camera's that can detect pests and diseases. For the detection of fruit tree canker the first algorithm was developed. Precision spraying during fruit thinning showed that aiming the trees with a high number of flowers gave the best effects on return bloom and that orchards will become more uniform. The **second example** is the development and or tests of sensor platforms that can detects blossoms and tree positions in the orchard or a platform that can examine the fruit quality of a storage bin. Specially for pear an algorithm was developed to measure the size. Colour measurements will follow in a follow-up project. The **third example** is the use of a non-destructive sensor to measure fruit quality like firmness and brix. The Fresco sensor showed reliable outcomes for both firmness as brix. And finally the **fourth example** is the build of end effectors for picking and pruning to make robots multifunctional. The first end effector to pick pears was made and tested with success in the field. This winter red currant plants will be pruned with the pruning end effector.

Objectives overall project

Making fruit cultivation more efficient, intelligent, sustainable, and future-proof requires us to be able to monitor, manage, and act at the level of individual trees. **Smart Technology** will enable getting the most out of an orchard through the targeted, efficient use of crop protection agents, plant hormones and fertilizers, while saving on labour and minimizing food waste. This all contributes to the creation of a sustainable fruit cultivation system.

The project has therefore three key objectives in relation to technology development:

1. Improving the sustainability of cultivation and the supply chain by:
 - a) developing ways of applying crop protection agents, plant hormones or fertilisers to individual trees (or parts of trees) based on new ways of detecting stress, pests, and diseases (using sensors and new algorithms) and
 - b) by combining data to develop new decision support models using AI. This will, for example, give decision support in storage duration and conditions to prevent loss and waste of the fruit, or help to determine the optimal dose of crop protection agents, growth regulators and fertilisers.
2. Maximising yields by optimising cultivation and storage through the optimisation of individual tree growth.
3. Minimising costs by developing multifunctional robots to replace human labour and ensure the efficient use of inputs.

The need to achieve these objectives has led to the project being organised in four case studies. A brief description of the four case studies is provided below, including an explanation of how they mutually reinforce each other.

Case study 1: Further development of precision sprayer

The former project Fruit 4.0 demonstrated that precision spraying at the level of individual trees is possible. In The Next Fruit 4.0 we want to further develop and broaden the application of precision spraying by controlling it down to individual nozzles and by using sensors to detect pests and diseases and apply sprays in response. Being able to control sprays at the level of individual nozzles also optimises the use of regulators for growth and fruit setting, resulting in a more uniform orchard. Hot spots of insect infestation can also be controlled without spraying the whole orchard.

Case study 2: Advanced crop management and yield registration

This case study is based on the use of sensors to collect data and translate it into decision support models visualised as clear dashboards. This will involve making the sensor platform from the Fruit 4.0 project applicable to more than just apples. The wide range of data and information gathered will also be distilled into clear insights around cultivation management. With help from experts and the use of modern AI algorithms, decision models will be created that can contribute to optimising and improving the sustainability of fruit cultivation.

Case study 3: Cool data

Apples and pears are often stored for a long time, even up to the following harvest. Storing the fruit for any length of time often leads to substantial losses due to a lack of clear, objective information on how long a particular batch can be stored. This case study will focus on maximising the use of data derived from the cultivation phase (climate, crop, and soil) and the focused application of new technology (sensors), leading to decision models that deliver better risk assessments and storage strategies. This will help reduce loss and waste during storage.

Case study 4: Multifunctional robot

Finally, The Next Fruit 4.0 will also work on expanding the functionality of existing robots which are already in development (e.g. by adding a gripper for picking pears, or for pruning and

removing suckers) and which could perform more efficiently through technological improvements and better orchard design. All of this will help solve the problem of increasingly limited availability of seasonal labour.

Results of the projects are presented per case study.

Case study: Precision sprayer

Objectives on building precision sprayer

A validated prototype precision sprayer for several fruit crops, which is directed at nozzle level on the basis of smart algorithms and decision models and combined with stress, disease and pest detection.

Significant Findings

- Laser scanner data can be translated into spray actions
- 2 prototype sprayers were build
- Both prototypes were tested in the field.
- Munckhof is already selling the sprayer developed in this project to the first customers.
- Factors that influence successful market introduction focus on compatibility (brand-independent integration), plug-and-play (simple operation), and techniques that allow growers to be independent.

Methods

The project concentrated on:

- Building 2 prototype sprayers with Pulse Width Modulated nozzles together with the manufacturers KWH and Munchhof.
- Building an improved sensor platform for the sprayers with LIDAR and GPS.
- Processing data into usable data for spray decisions at nozzle level based on tree volume.
- Tested the sprayers on leaf deposition and also on savings on spray volume.

Results and Discussion

In practice, the most important benefit is that in the future fewer spray volume will be needed to achieve the same result and that emissions to the environment will be further limited. The LIDAR scanners that make this possible are placed at the front of the sprayer. They determine the tree volume and gaps while driving. Both spray systems use PWM (Pulse Width Modulation) technology to vary the amount of spray liquid. This is done by changing the length of those pulses. Based on the tree volume an algorithm determines the amount of spraying liquid for each nozzle. Munckhof build their own algorithm and KWH used an algorithm developed in this project by Wageningen University & Research.

At the end of the project both sprayers were working and were tested in the orchard. The deposition on the leaves with the use of the sensors turned on were as good as when the sprayer did not use the sensors. If the deposition was not as good, it would have meant that the nozzles sprayed too late. The savings were around 15% in summer, during spring this can be better. Also the settings are very conservative so it will not miss anything. The optimum settings still need to be determined. Also the PWM nozzles are set to be turned on or off, in other words they spray at 100% capacity or 0%. In a future project the sprayer will be able to spray a lower amount (between 0-100%) if the density of leaves is less. In that way, more spraying product can be saved.

Below 2 pictures of the sprayers, one in the field during tests and one during installation of the components.



Objectives work on economic validation and innovation adoption

Within this work package work is also done on the economic validation and innovation adoption of a precision sprayer. This research clarified the factors that influence successful market introduction. This includes, on the one hand, economic feasibility and, on the other, factors that can drive or hinder the implementation and/or user acceptance of technological innovations for fruit growing.

Methods

The preconditions for faster practical adoption of new precision technologies were examined. The focus is on which factors influence the purchase of a precision sprayer or the use of precision features on the sprayer. Interviews were conducted with growers, advisors, dealers, manufacturers, and/or developers. The questions are based on the Behaviour Change Wheel method (see figure below).

This allows us to:

- Conduct a behavioural analysis: which behavioural characteristics play a role in the use or non-use of the precision sprayer?
- Diagnose what needs to change.
- Identify which interventions are likely to bring about behavioural changes.



Results and Discussion

The following interventions can help accelerate the adoption of precision spraying techniques. Work with growers as ambassadors and role models. A success story told by a grower is the most convincing. As developers, **focus on compatibility** (brand-independent integration), **plug-and-play** (simple operation), and techniques that **allow growers to be independent** from other companies like in the case of hiring a drone pilot to scan the orchard versus having a sensor platform on their own so they can scan any time they want.

A recommendation at the system level is to develop a shared strategy and vision for the sector, focusing on "it is important for health and the environment that we reduce crop protection options, and precision farming is the way to make this possible and thus the future." The second recommendation is to adapt legislation to the possibilities of precision farming. Legislation currently lags behind the possibilities of precision farming (for example: adjusting the maximum

number of applications per plot per year to the maximum amount of permitted pesticides per plot per year).

Case study: Advanced crop management and yield registration

Objectives

- Validated sensors and algorithms to collect physiological and phytopathological characteristics of apple and pear.
- Validated decision models developed on the basis of collected data and expert knowledge; targeted on production optimization.

Significant Findings

- Trunk detection to get the GPS locations for individual trees.
- Detection method to detect fruit tree canker and apple blossom weevil
- Proof of principle was demonstrated for automated detection of pear in top layer of storage bins.
- Experiments were done to develop a thinning decision support system for Conference pear.
- Field trial on blossom and fruit thinning showed that precision spraying on trees with a high amount of flowers is the most effective strategy to make the orchard more uniform. Stimulating trees with a low number of flowers is less effective.

GPS position of trees

Methods

In this part of the research, sensor platforms of Aurea Imaging and AgroWizard were used to see if they are able to detect the GPS position of trees. This is relevant if orchards were not planted with GPS and the grower wants to use precision fruit thinning.

The sensor platform of Agrowizard is mounted on a quad and scans the trunks. Combined with the GPS and an algorithm it determines the GPS position of the trees (picture below with setup). The system of Aurea Imaging is mounted on the top of the tractor. The camera's face downwards to scan the trees but also the trunks during winter time. During the summer, this is not possible. With Agrowizard system 6 orchards were scanned with 86-162 trees per orchard and with the Aurea Imaging setup, 2 orchards with 64-96 trees. Outcomes were compared with GPS measurements done with a handheld RTK-GPS.



Results and Discussion

The Agrowizard system could determine 69% of the trees position within an error margin of less than 10 cm (~ 4 inches). With a higher error margin of 20 cm, 92% of the trees could be determined. An error margin of 20 cm (~ 8 inches) is found to be enough for most of the growers to use precision fruit thinning.

The Aurea Imaging system found 47% of trees within the 10cm error of margin and 89% within the 20cm error of margin.

For both system the challenges were orchards with slanting trees or with interfering elements like nets to protect the trees against wildlife

damage. Aurea Imaging will have an option in the future to position their sensor platform to a lower position in order to be able to detect the trunks in a better way. But with those 2 systems, it is now possible for growers to start using precision spraying in older orchards. The same camera

systems can be used for other things as well, like detection of blossoms, fruits and diseases. In the project algorithms to detect the disease fruit tree canker and the pests apple blossom weevil were developed. Further development is still needed to be able to use the algorithms on a commercial level.

Image processing photos storage bin

Methods



Within the project, WUR was developing image processing in which the size distribution of the pear is initially determined from photos of the storage bin. In subsequent steps, other quality aspects can also be analysed, such as fruit shape, colour and certain damages. For the size measurement specific points in the shape are now detected. This concerns the stem and nose position and the widest point of the fruit to determine the diameter. Several steps are required to validate the data. First, it must be determined how reliable the size measurement for the detected pears is and then it must be determined how well this size distribution corresponds to the entire storage bin or the entire batch.

Results and discussion

The performance of the various AI models (developed in 2023 and optimized in 2024) and combination of models were tested on pears. The maximum deviation in size was determined, for both size and weight. The best model for size had a deviation of deviation 3.8 mm (0.15 inch), while another model was better to determine fruit weight (deviation 24.8 grams/ 0.055 pounds). The image processing model is running on a trial basis at the project partner Bodata. The goal is to bundle the collected information into a quality report. We are currently discussing with the consortium partners involved how the analyses can be incorporated into daily practice. Preparations are also being made for market introduction.



Because there is little time during the harvest to photograph each storage bin by hand, it was suggested that it would be practical to drive a picking train under a gate where the photos could be taken automatically. By then linking the photo to this storage bin via an RFID chip, it will be possible to quickly gain insight of a complete batch.

A test setup was tested at the experimental orchard Randwijk during a harvest period. As soon as a storage bin passes the camera, a photo is automatically taken and the RFID chip is scanned. To ensure consistent photo quality, it was decided to shield the portal from daylight and artificially illuminate it with construction lights. To minimize motion blur in the photo, the picking train had to pass in the lowest gear. Integration with RFID stickers turned out to work fine. There are still some points that require attention, such as fruit brilliance and colour correction. The latest insight is that growers prefer a setup on a forklift. This idea will be

examined in another project.

Precision thinning

Methods

Extensive thinning tests were done at the Experimental orchard in Randwijk on Elstar apple and Conference pear during the course of the project. Different thinning treatments were done with a

focus the product Brevis. Those treatments were done *on the whole* orchards or *based on a task map* and compared with *an untreated* orchard. In the task map the trees with a high amount of flower clusters got the strongest thinning treatment, the middle group of trees got the standard treatment and the trees with a low amount of flowers got nothing.

Counting was carried out at three times, namely at the end of June (end of June drop), in July (hand thinning) and in August (just before harvest). Just before harvest, a random fruit size measurement was also carried out in all treatments.

Results and discussion

Precision thinning in the Elstar apple variety has several advantages: 1) avoiding chemical thinning in the lowest flowering class prevents yield loss, 2) a significant reduction in the required manual thinning when thinning according to the task map is possible, particularly in the highest flowering classes, 3) in the case of a high flower cluster numbers, overthinning is less likely to occur.

By applying precision thinning according to the task map, each flowering class can be given the optimal thinning strategy, making it easier to achieve the target number fruits/tree in more trees; the orchard becomes more uniform and alternate bearing in the following year is prevented.

In Conference pear, applying fruit thinning in the "high" flowering category results in a reduction in the number of fruit per tree, and gave a higher average fruit weight, resulting in a comparable net yield in kg. This can reduce the labour required for hand thinning and harvesting.

In the figure below the effect of precision spraying is clearly demonstrated. In the untreated block the different categories of trees from low to high numbers of flowers, show a different size distribution at harvest time. In the case of the orchard were each category got another treatment the size distribution is uniform.

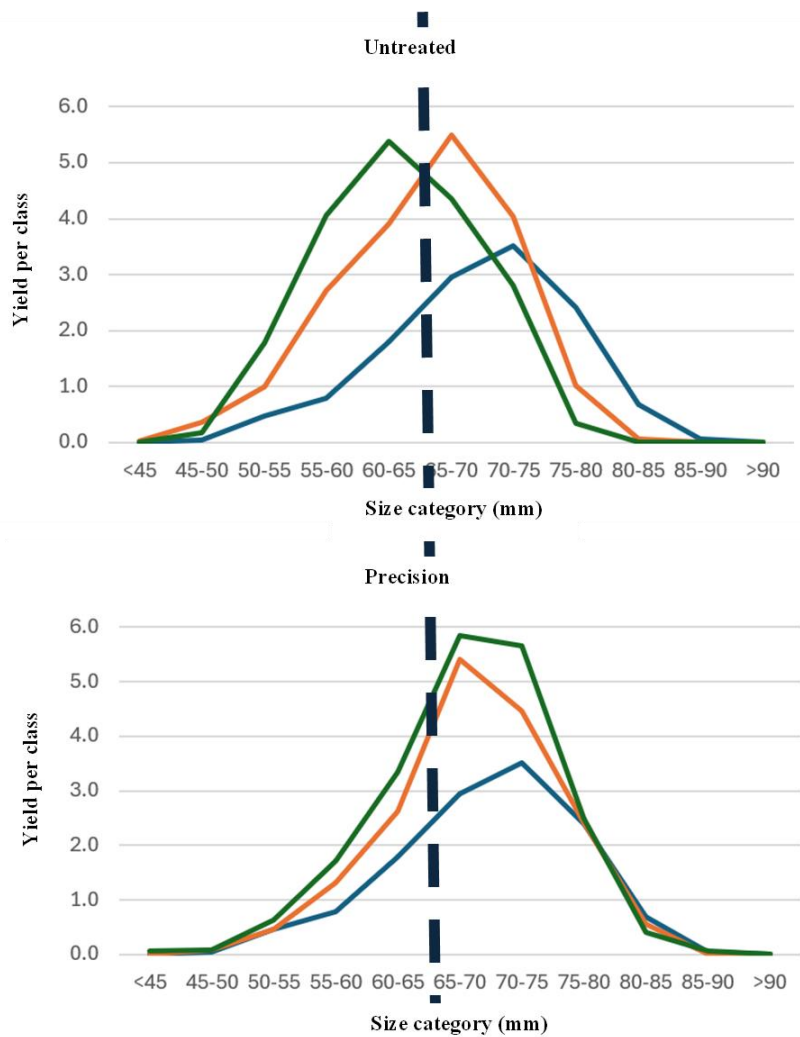


Figure: blue line: low amount of flowers, orange: normal amount, green: high amount of flowers.

Develop crop growth model

Methods

Within this work package, Delphy is working on developing a crop growth model for pear (Conference). The aim is to predict the June drop and the final fruit numbers for Conference pear. Many counts and measurements were again carried out in various tests from 2021-2024. In addition to validating the model, work has been done to collect information about the course of the June drop and the factors that influence it on 3 different pear orchards.

Results and Discussion

It was found that it is possible to determine the leaf development based on degree days as is shown in the figure below. It was also found that the chance of a fruit drop is determined by the relative growth of the growth of the pear. This can be described by formulas. The measurements are plotted in the figure below. Camera systems with the right resolution could in the future follow the growth of pears and predict the fruit drop in a better way.

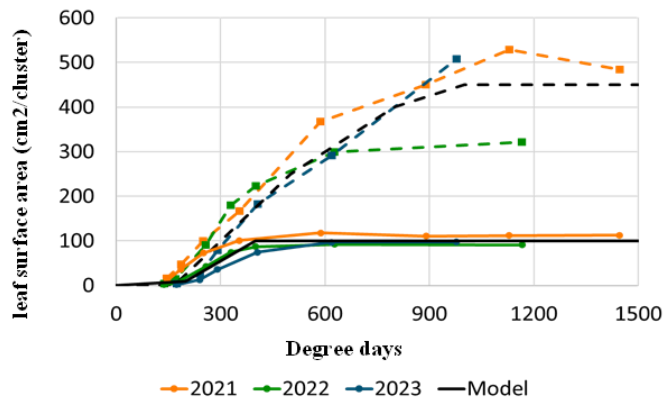
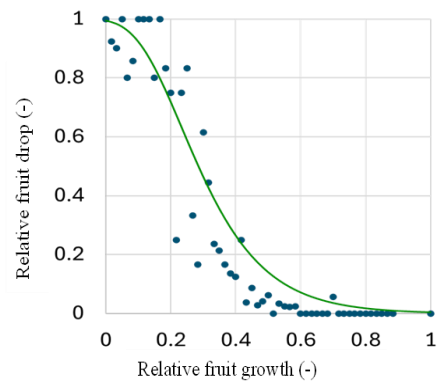


Figure: Development of cluster leaves (solid lines) and shoots (dotted lines) in 2021-2023.



The probability of a pear falling or remaining stuck depends on its relative growth. Example: May 2022.

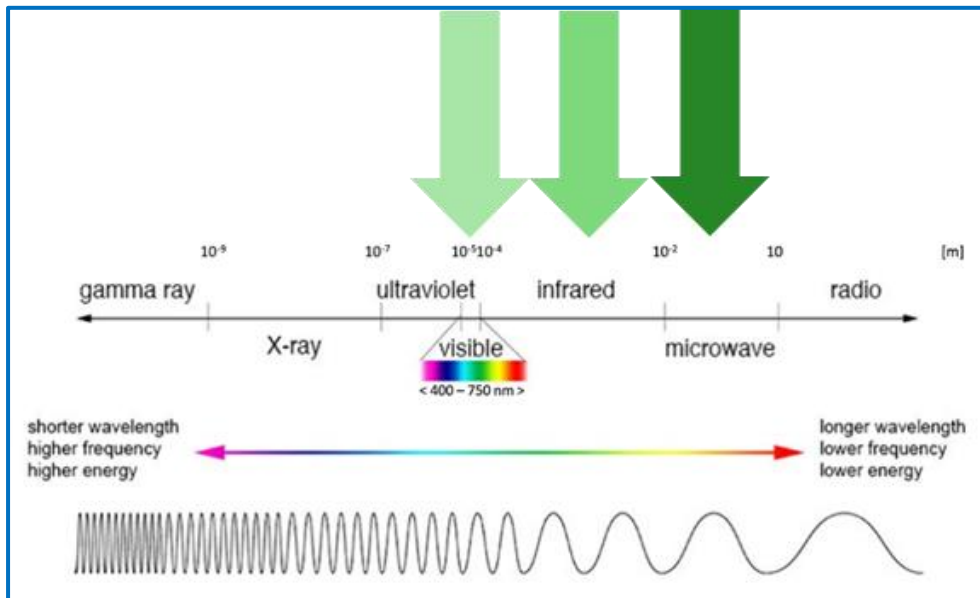
Case study: Cool data

Objectives

This project investigated two techniques for non-destructively measuring the internal fruit quality of Conference pears. Both utilize electromagnetic waves from the invisible part of the spectrum. Kubota investigated the application of Near Infrared (NIR) technology, while Vertigo investigated the application of Microwave technology.

Significant Findings

- It was possible to measure the Brix with both systems but measuring the firmness was only possible with the Fresco scanner from Vertigo.



Methods

First the tools to evaluate the fruit have been selected. Non-destructive measurements using new tools are being related to common (destructive) quality assessment methods.

Common quality assessment

- Firmness, Brix, Weight
- Photographic analysis (colour, shape, percentage russeting)

Non-destructive assessment

- Near Infrared – both a hand held sensor from the project partner Kubota and hyperspectral imaging from our in-house facility
- Microwave based – a hand held sensor from the project partner Vertigo



The project partner Kubota decided to pause the further development of the NIR hand held sensor. Therefore the focus was on Fresco sensor from Vertigo.

Companies were visited in the most important Conference growing regions (Limburg, Zeeland, the Betuwe, Utrecht, Flevoland, North Holland and the Belgian fruit region). In some cases, the storage boxes were labelled so that they can be reanalysed as soon as they leave storage. Fruits from each batch were collected and stored in parallel at WUR Randwijk. Photo material and data about firmness and sugar content are added to the Agromanager database as much as possible. Agromanager is data platform for fruit growers where all data can be collected and analysed by the grower.

Results and Discussion

Both Kubota and Vertigo meters are suitable for non-destructively measuring Conference Brix. The Vertigo meter (Fresco) is suitable for non-destructively measuring Conference firmness. Although the Brix is easier than the firmness. The nice thing about the hand held sensor is that multiple measurements can be taken to get a better average firmness value. In consultation with Vertigo, a plan is being developed to launch the Fresco.

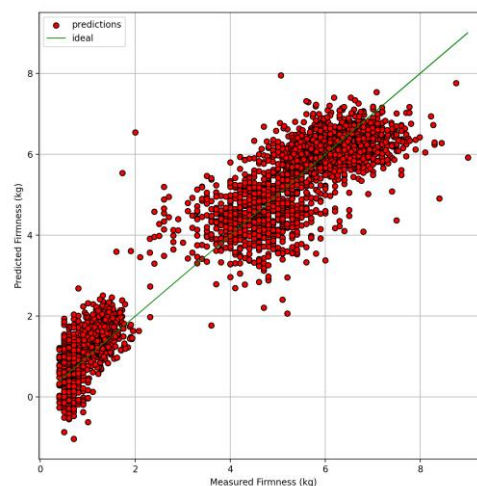
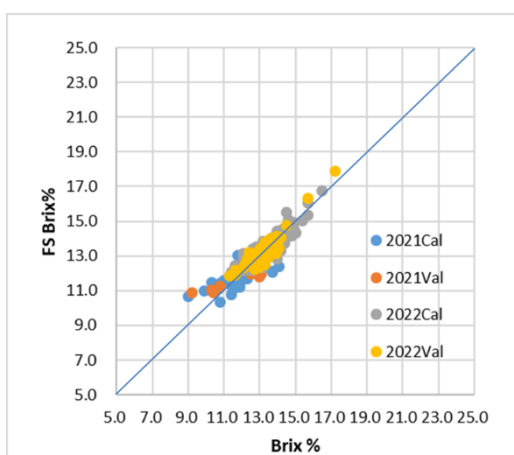


Figure: on y-axis predicted Brix value and on the x-axis the measured ground truth data of Brix.

Figure: on y-axis predicted firmness value and on the x-axis the measured ground truth data of firmness.

Case Multifunctional robot

Objectives

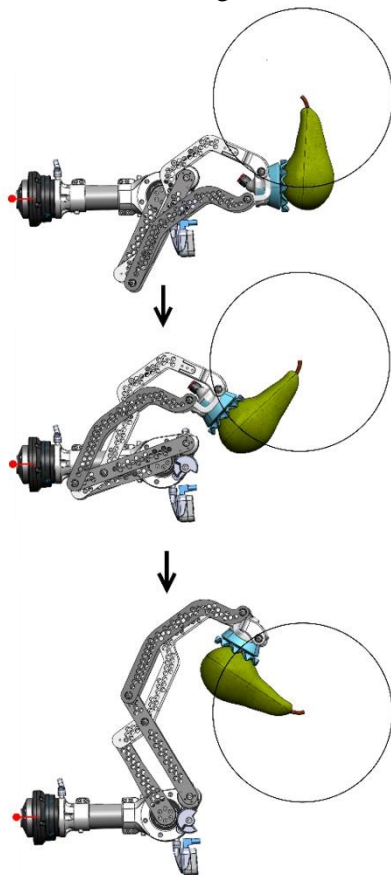
The main objective of the multifunctional robot case is to expand the functionality of existing orchard robots and of orchard robots currently under development in parallel research projects. The focus of the work is on two topics, namely the development of a sensing system and a gripper for picking pears and on a sensing system, robot control and end-effector(s) for robotic pruning of fruit trees and red currant bushes. On the longer term additional tasks such as automatic thinning, removing weeds and precision spraying will be targeted.

Significant Findings

- Detection system developed for robotic harvesting pear to detect the position but also the orientation and some other key points of the fruit.
- Prototype gripper that can do the required motion to detach a pear from a tree which is significantly different from that to detach an apple.
- Extensive knowledge and expertise on automatic pruning and fruit harvesting is exchanged with Washington State University and Oregon State University. Close cooperation and knowledge exchange between Dutch and US researchers is of mutual benefit.
- A prototype gripper for pruning is developed and tested on red currant.

Methods

When harvesting by hand, the pear is often lifted perpendicular to the stem, causing the pear to detach from the tree during the natural separation of the stem. The new pear gripper concept uses the same



motion. A soft silicone suction cup uses a vacuum pump to grip the pear. The key innovation of the pear gripper lies in the lifting motion that is integrated into the gripper mechanism. This means the robot arm no longer has to perform this motion itself. This increases the picking speed and reduces the risk of collision between the robot arm and the tree.

A small stereo vision camera attached to the gripper detects and locates ripe pears. This information is passed to the control software, which calculates the correct path for the robot arm to grasp and pick the pear.

To detect the pear and estimate its grasp point, Deep-Learning Keypoint R-CNN is used. This algorithm is a region-based convolutional neural network (R-CNN) that can simultaneously detect the object (the pear) and the grasp point (a point on the pear) in an image. Not only the position of the pear but also the grasp point can be learned end-to-end using hand-labeled training images.

The robotic arm systematically moves the gripper with the camera along a preset search frame approximately 20-30 cm from the tree. Upon detection, the pear is harvested immediately. If multiple pears are detected in a single frame, the pear closest to the robotic arm is picked first, as this is generally the easiest to reach.

Results and Discussion

During the harvest period in September 2023, WUR conducted experiments with this setup at the experimental fruit research station Randwijk to harvest Conference pears. The results are convincing: the robot can detect and harvest pears without damaging them. The

tests in the orchard provided valuable insights into what works well and what can be improved on the gripper. For example, some fruits are difficult to reach, and the lifting mechanism only works optimally for a predetermined fruit size. Furthermore, the robot does not yet detect obstacles, such as branches or crop wires. This can be risky for both the tree and the robot. The gripper is therefore not yet ready for practical introduction, but it is an important piece of the puzzle for the development of future robots for fruit growing.



Photo 1 Robot setup in orchard



Photo 2 Gripper with suction cap

Pruning red currant bushes

Methods

The main challenge in the end-effector for pruning lies in the sensors responsible for determining the correct pruning positions. Electric battery-powered pruning shears for manual pruning have developed into robust systems over the years. For this reason, it was decided to use an existing pruning tool (Makita DUP361ZN) and modify it so that it could be controlled by the robot. This pruning shear is capable of cutting branches with a diameter of up to 33 mm. To operate this tool safely, a digital output signal from the robot was converted into a mechanical input to actuate the lever in the tool. This was achieved using a coil with an electromagnet. To accommodate this additional component and enable mounting on the robot flange, a new 3D-printed housing was designed. The power for cutting is supplied by two 18V 5.0Ah batteries. These can cut over 70,000 times on a single charge.

The camera system's task is to determine which branch the robot should prune, and where. In addition to colour information, this requires 3D information. A stereo camera (Intel RealSense D405) is mounted on the end-effector for this purpose. This small and lightweight camera (4.2 cm × 4.2 cm × 2.3 cm; 60 g) provides colour and 3D images between 7 cm and 50 cm. This makes the camera suitable for detecting detailed features or improving target position estimation based on additional sensors on the robot. The completed prototype of the pruning end-effector is shown below. Linux and the Robot Operating System (ROS2) are used to control the end-effector, the camera, and the robot.



Conclusion and discussion

Experiments in the lab and outdoors with redcurrant have confirmed that it is possible to prune branches using a robot arm and this end-effector. The prototype end-effector for pruning meets the wishes and requirements defined in the project. In addition to pruning redcurrants, this prototype can also be used to prune large fruit. The prototype does not yet meet all the requirements of a commercial product, such as watertightness. The biggest challenge for robotic pruning is not the pruning shears themselves, but sensors and algorithms for detecting the correct pruning positions.



Project Title: Pear Rootstock Breeding

Report Type: Continuing Project Report

Primary PI: Kate Evans

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Address 2: 1100 N. Western Ave

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Cooperators: Amit Dhingra, Jessica Waite, Chris Gottschalk

Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$ 100,637

Total Project Request for Year 2 Funding: \$ 109,831

Total Project Request for Year 3 Funding: \$ 109,747

Other related/associated funding sources: Awarded

Funding Duration: 2025 - 2028

Amount: various

Agency Name: Pome fruit breeding program royalties

Notes: apple royalties used to supplement staffing, orchard and lab equipment, collaborative genetics/genomics research with cooperator Waite (including graduate student tuition as appropriate), conference travel costs, publication fees.

WTFRC Collaborative Costs: none

Budget 1

Primary PI: Kate Evans

Organization Name: Washington State University Tree Fruit Research & Extension Center

Contract Administrator: Kevin Rimes

Telephone: 509 293 8803

Contract administrator email address: kevin.rimes@wsu.edu

Item	07.01. 2025	07.01.2026	07.01.2027
Salaries ¹	\$57,600.00	\$59,904.00	\$62,300.00
Benefits	\$20,261.00	\$21,072.00	\$21,914.00
Wages ²	\$7,997.00	\$8,317.00	\$8,650.00
Benefits	\$805.00	\$838.00	\$871.00
Supplies ³	\$2,000.00	\$6,000.00	\$2,000.00
Travel ⁴	\$1,960.00	\$1,960.00	\$1,960.00
Plot Fees	\$4,514.00	\$6,240.00	\$6,552.00
Miscellaneous ⁵	\$5,500.00	\$5,500.00	\$5,500.00
Total	\$100,637.00	\$109,831.00	\$109,747.00

Footnotes:

¹Salaries for research associate who is the point person for pear rootstock;

²Wages for time-slip labor for orchard management and trait phenotyping;

³Planting, greenhouse and orchard supplies;

⁴In-state travel between TFREC and orchards for orchard management and trait phenotyping;

⁵Propagation

Objectives

- 1. Develop and evaluate seedling populations to produce new rootstocks**
- 2. Establish a replicated Phase 2 evaluation orchard of rootstock selections**
- 3. Build on genomics collaboration for identification of key target loci**

Significant Findings

1. Seedling populations budded with d'Anjou were evaluated for the traits listed in Table 2.
2. 1400 new pear seedlings were screened for resistance to fire blight in the greenhouse in spring 2025.
3. Ten selections consistently showed little to no susceptibility to greenhouse fire blight testing and are now propagated and growing in the greenhouse in preparation for budding for Phase 2 trials.

Methods**Objective 1. Develop and evaluate seedling populations to produce new rootstocks**

Approximately 1,300 seedlings (budded with d'Anjou) segregating for vigor, precocity and other horticultural traits are established at the WSU Columbia View orchard for continued evaluation of vigor/dwarfing potential. Rootstock and scion traits have already been collected (as shown in **Table 1**) and will continue for up to three more years to enable accurate selection.

Approximately 1400 new pear seeds produced in 2023 are currently germinating and will be screened for resistance to fire blight in the greenhouse in spring 2025. Survivors will be planted in the orchard and budded for evaluation.

Cross year	Number of seedlings	Data collection	
		Rootstock traits	Scion (d'Anjou) traits
2017	~320	Branch angle (2020) Presence of spine (2020)	Branch angle (2023-24) Floral bud count (2023-25) Internode length (2022) Scion growth (2022-24) Trunk diameter (2022-24) Budbreak (2022-25)
2019	~1,000	Branch angle (2022) Presence of spine (2022)	Branch angle (2024) Floral bud count (2023-25) Internode length (2023) Scion growth (2023-24) Trunk diameter (2023-24) Budbreak (2023-25)

Table 1: Rootstock and scion traits on active seedling populations already collected prior to the start of this project.

Objective 2. Establish a replicated Phase 2 evaluation orchard of rootstock selections

Evaluation of the 2016 seedling families was completed with forty-two individuals selected in summer 2024, moving ahead of the expected timeline shown in Figure 1. Tissue was sent to Qualterra for micropropagation. In addition, seedling trees were cut back to below the graft union and mounded with sawdust to encourage production of rooted suckers. The aim is for sufficient material to test for fire blight resistance in the greenhouse in spring 2025 and to establish a subset of individuals into a Phase 2 randomized replicated trial within the timeframe of this proposal. The final trial plan will depend on the number of available viable rootstocks of each accession but will take into account the number of replicates, possible different scions and will include comparison standards for reference. The current plan is to plant this trial at the WSU orchard, however once final numbers are determined, the option of siting with a local grower collaborator will be explored.

Objective 3. Build on genomics collaboration for identification of key target loci.

The DNA region associated with dwarfing that was identified in a previous project (PR-22-102), and contains many genes. Fine-tuning to identify the specific gene sequences associated with dwarfing would aid in future breeding selection, possible gene-editing, and the identification of genetic pathways involved in this phenotype. In collaboration with Dr. Waite (USDA-ARS, Wenatchee), the effort to add precision to this region using a new computational tool (Khufu) to identify genetic variants in our data set continues. Analysis has been slower than expected with the provider (Hudson Alpha). A new collaboration with Dr. Gottschalk (USDA-ARS, Kearneysville), who has experience with similar data sets, should facilitate progress.

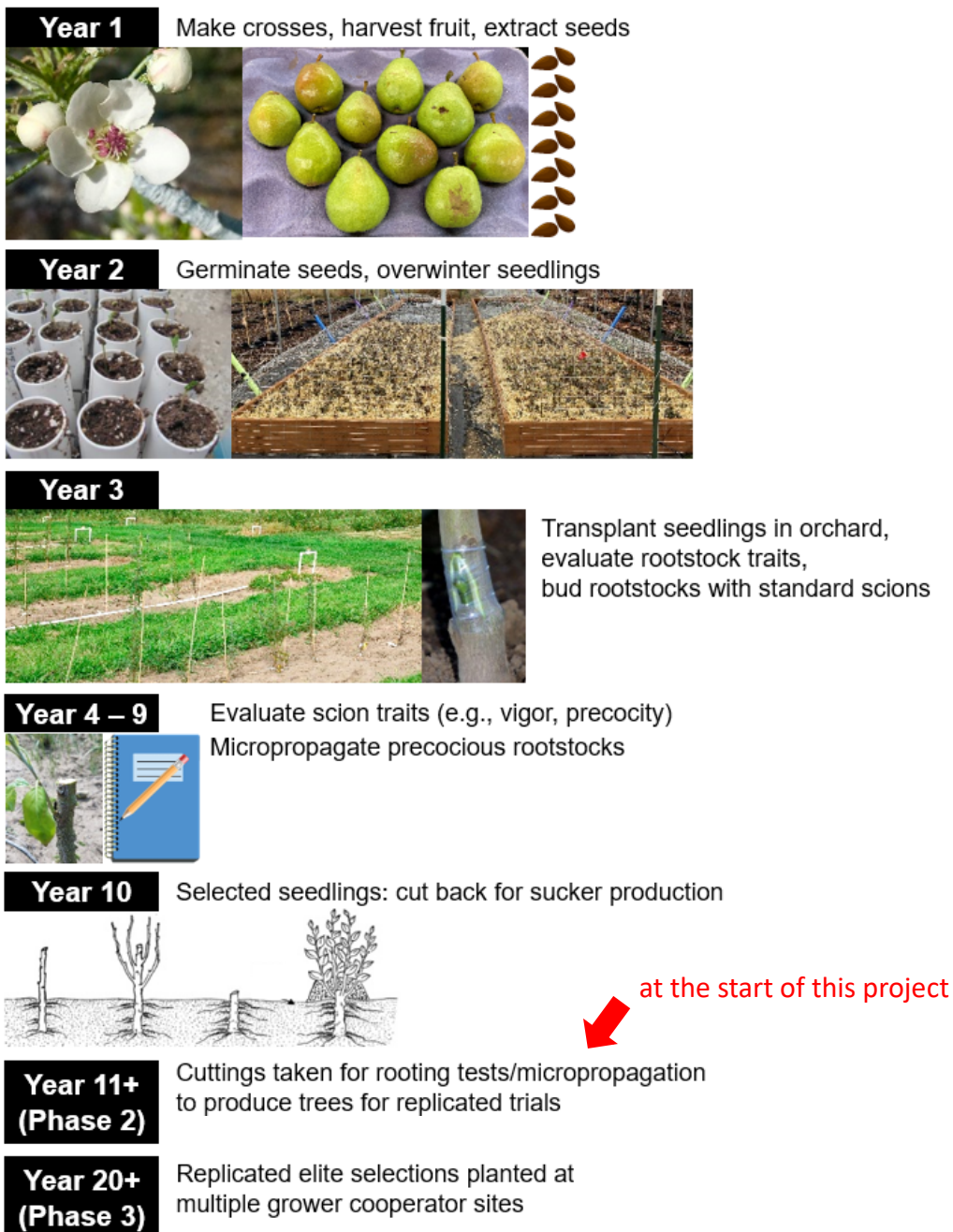


Figure 1: Timeline overview of the WSU pear rootstock breeding program in developing new dwarfing pear rootstocks.

Results and Discussion

Objective 1: Develop and evaluate seedling populations to produce new rootstocks

Cross year	Number of seedlings	Phenotypic data collected in winter 2025/2026
2017	~320	Number of suckers
2019	~1,000	Number of suckers Internode length Scion growth Scion trunk diameter Tree height

Table 2: Phenotypic data of rootstock and scion (i.e., d’Anjou) traits collected for *Pyrus* seedling populations in winter 2025/2026.

Objective 2: Establish a replicated Phase 2 evaluation orchard of rootstock selections

Forty-one of the forty-two individuals selected in summer 2024 were successfully micropropagated by Qualterra and delivered to the TFREC in three batches (January, April and May 2025). Production of rooted suckers in the orchard was less successful with very few selections forming roots. The micropropagated selections were tested for susceptibility to fire blight using the cut-leaf method in the greenhouse (May/June 2025). All but three of the selections had at least 10 replicates inoculated; only 5 replicates were included of the remaining three selections due to low numbers of available plants. Ten selections showed very low susceptibility to fire blight and are moving forward in the program. After receiving several chill months in the tree store, they are currently growing in the greenhouse until they are large enough to plant out in the nursery for budding.

Objective 3: Build on genomics collaboration for identification of key target loci

Due to USDA-ARS personnel cuts and the government shut-down, very little progress has been made on this objective. We are exploring other ways to pursue this, possibly with a graduate student.

Progress of the project was reported in the Good Fruit Grower (September 2025) Vol. 76, No. 14 page 8.