Project/Proposal Title: Retraction of netting near harvest: risks vs. rewards

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Report Type: Continuing Project Report

Project Duration: 2-Year

Total Project Request for Year 1 Funding: $ 37,761
Total Project Request for Year 2 Funding: $ 39,107

Other related/associated funding sources: Requested
Funding Duration: 2023 - 2028
Amount: $6.5 million
Agency Name: USDA SCRI
Notes: This was our third time submitting this proposal that is focused on mitigating the impacts of temperature extremes on pome fruit. While not funded, it was, again, ranked highly and will be resubmitted in 2024.

WTFRC Collaborative Costs: none

Budget 1
Primary PI: Lee Kalcsits
Organization Name: Washington State University
Contract Administrator: Darla Ewald
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Station Manager/Supervisor: Chad Kruger Email Address: cekruger@wsu.edu

Item	2021	2022	2023
Salaries	17,514[1]	18,215[1]	
Benefits	6,548[1]	6,811[1]	
Wages	7,800[2]	8,112[2]	
Benefits	1,749[2]	1,819[2]	
Equipment			
Supplies	3,000[3]	3,000[3]	
Travel	1,150[4]	1,150[4]	
Miscellaneous			
Plot Fees			
Total	37,761	39,107	0

Footnotes:
[1]Funding is requested for a scientific assistant at 35% during August to November of each year of the project. Benefits rates for the scientific assistant are equal to 37.4%
[2]Funding is requested for a summer staff member to work on netting set up at Sunrise research orchard, fruit thinning and horticultural management, and experimental set up in August. Benefits for this position are equal to 22.4%
[3]Supplies are for netting set up and consumables for field and lab experiments that may include new data loggers, solar panel hardware, as well as lab supplies for fruit quality analysis.
[4]Funding for travel is requested for weekly trips to Sunrise research orchard as well as twice-weekly trips to Quincy in August and September for conducting retraction experiments.

OBJECTIVES

This project had two objectives aimed at quantifying risks and rewards of using retractable netting systems for high-value apple cultivars.

1. Test the timing of retraction of netting across two growing seasons to determine how much netting retraction enhances red color development and how close to harvest deployment should occur.
2. Determine whether fruit under netting is at a greater risk of developing sunburn when netting is retracted.

SIGNIFICANT FINDINGS

- **Netting had the greatest benefit to reducing sunburn and EC reduced severe sunburn when used in conjunction with retractable netting systems. Evaporative cooling alone was not sufficient to limit sunburn development on fruit in 2021.**
- **After two seasons, retraction 7 days before harvest had equal red color as when netting was retracted 14 days before harvest. While netting retraction had a significant benefit in 2021, it did not in 2022 for the commercial trial. However, color development was extremely poor in 2022 for Honeycrisp across the state and as such, differences between treatments were not as great.**
- **When comparing additional losses from sunburn to gains in red color in 2021 and all other things being equal, these changes translated to an additional 1.5 packed boxes per bin when retraction was used compared to leaving netting in place. These differences were mostly consistent between the commercial and research orchard locations. In 2022, the commercial orchard only had an additional 0.25 packed boxes per bin.**
- **When these differences are calculated for a 60 bin/acre crop and a box price of $56/box, it translates to an additional $5040/acre in revenue in 2021 and only $840/acre in 2022 for the commercial orchard site. Note: Fruit prices are variable, please price out benefits based on current market pricing and color and sunburn thresholds for those markets.**
- **There was no evidence of the development of photo oxidative sunburn from removing netting prior to harvest even when netting was retracted at higher temperatures (above 100 °F in 2022).**
- **No increases in postharvest disorders were observed after three months of storage at 35 °F in regular atmosphere.**

METHODS

Experiment 1: Removal timing for netting retraction

This experiment was performed in a Honeycrisp orchard that was planted in 2018. It consisted of Honeycrisp on G890 rootstocks planted to a tall spindle training system. Netting was installed and

covered the orchard in 2020 consisting of a panel and cable system that extends over the entire orchard. Each panel was 55' wide and covers 4 rows. In August, 14 days before harvest, in 2021 and 2022, netting was removed from a 55' section within the block. Then, 7 days before harvest another 55' wide section will be retracted. These two treatments were compared against a control that was left covered until after harvest. These treatments helped determine the impact of duration of retraction before harvest on color development for previously netted trees.

Measurements (Summarized in Table 1):

Fruit surface temperatures were continuously measured for 8 days to determine if there were differences in fruit surface temperatures of fruit between treatments. To assess fruit quality for each treatment, 100 fruit were harvested from the upper canopy area of each replicate to look at sunburn incidence and fruit color development. After harvest, fruit was run on an AWETA sorting line that can measure fruit diameter, weight, red color coverage and intensity as well as background color. Sunburn incidence and severity was graded on all fruit using a six-point scale adapted from Schraeder et al. (2003).

Table 1. Measurements made on fruit in the orchard and at harvest for experiment 1 which is focused on identifying optimum timing of net retractions near harvest for Honeycrisp apple.

Measurement	What	When	Where	Why
Fruit surface temperature	Thermocouples	Entire duration of the experiment in 2021 and 2022	Two trees per replication and four fruit per tree	Assessing sunburn risk and differences in acclimation between treatments
Fruit sizing	AWETA Sorting Line	Within one week of harvest	WSU TFREC	Grading for size, color area, and color intensity
Sunburn incidence and severity	Graduate student and technician	One week after harvest	WSU TFREC	Assessing the impact of netting retraction on sunburn risk
Postharvest disorders	Graduate student and technician	January 2022	WSU TFREC	Assessment of postharvest sunburn development along with other external and internal disorders that might emerge from retracting netting near harvest

Experiment 2: Combining netting retraction with evaporative cooling

This second experiment was conducted at the Sunrise Research Orchard in Wenatchee, WA in a top-worked Firestorm® Honeycrisp orchard that was regrafted in 2016. The experimental design had six treatments arranged in a split plot design with evaporative cooling treatments as a main plot and then

retraction as a secondary plot. There were three replications for each treatment. Netting was deployed in early June using a modified retracted netting setup from Extenday (See Figure 2). Evaporative cooling was available from June 15 to harvest with automated sprinklers that were triggered when air temperatures reached 85 °F. Cycling was set to be 15 minutes on and 30 minutes off during those times. Netting was retracted two weeks prior to harvest for replications with either evaporative cooling or no cooling and there was a completely uncovered control to compare all sunburn mitigation treatments against to look at effect on red color and sunburn.

Experiment 2 Measurements (Summarized in Table 1):

Thermocouples that measure fruit surface temperatures were installed on the day of retraction on four fruit on each of one tree per replicate. There was a total of 15 dataloggers used for the entire experiment in 2021 and 2022. Fruit surface temperatures were monitored for the whole 10 days to determine differences in fruit surface temperatures among treatments. Environmental conditions were pulled from the WSU AgWeatherNetwork (Sunrise Weather Station). Like experiment 1, fruit quality was assessed for each treatment. Approximately 100 fruit were harvested from the upper canopy area of each replicate to look at sunburn incidence and fruit color development. After harvest, fruit was run on an AWETA sorting line that can measure fruit sizing, weight, red color coverage and intensity as well as background color. Sunburn incidence and severity was graded using a six-point scale adapted from Schraeder et al. (2003). In 2022, fruit was also stored at 33 °F in regular atmosphere for three months to assess fruit quality after storage.

RESULTS AND DISCUSSION

Experiment 1: Retraction timing

For both years in the commercial trial, retraction produced higher proportions of fruit with premium red color coverage (>33%) but were not statistically significant ($\alpha = 0.05$). Whether retraction was done 14 days or 7 days before harvest had no difference in red color coverage or the proportion of fruit with premium red color (>33% coverage). Unsurprisingly, fruit weight was not affected by retraction timing. However, despite low statistical confidence that red color coverage was greater, Figure 3 shows that there was a higher visible red color presence when netting was retracted prior to harvest.

Table 2. Fruit weight, red color coverage, and sunburn for netting treatments in 2021. P-values were found using ANOVA tests in RStudio at alpha=0.05.

Treatment	Weight (g)	Red coverage	sunburn incidence	SB1	SB2	SB3	SB4
Retracted 14 days before harvest	300	56.7%	31.8%	15.7%	9.3%	4.4%	2.3%
Retracted 7 days before harvest	292	62.9%	28.1%	12.8%	7.9%	4.9%	2.5%
No retraction	285	53.5%	18.6%	9.5%	5.6%	2.7%	0.7%
P-value	0.7016	0.1722	0.1604	0.3152	0.3765	0.3597	0.3077

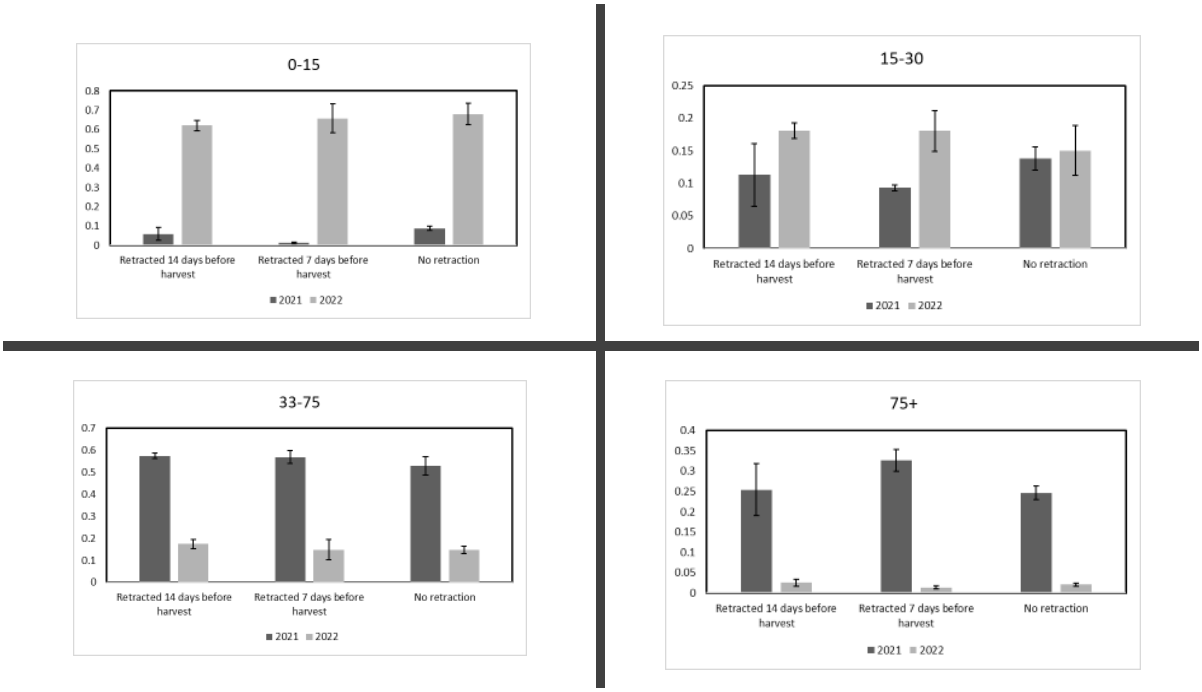

Figure 1. Mean proportions of total fruit (N=3) with red color at four different ranges of color coverage for Honeycrisp apple; 0-15% (top left), 15-30% (top right), 33-75% (bottom left), and 75%+ (bottom right) in 2021 and 2022 netting retracted 14 days before harvest, 7 days before harvest, or at harvest. No significance was found using ANOVA tests in RStudio at α=0.05.

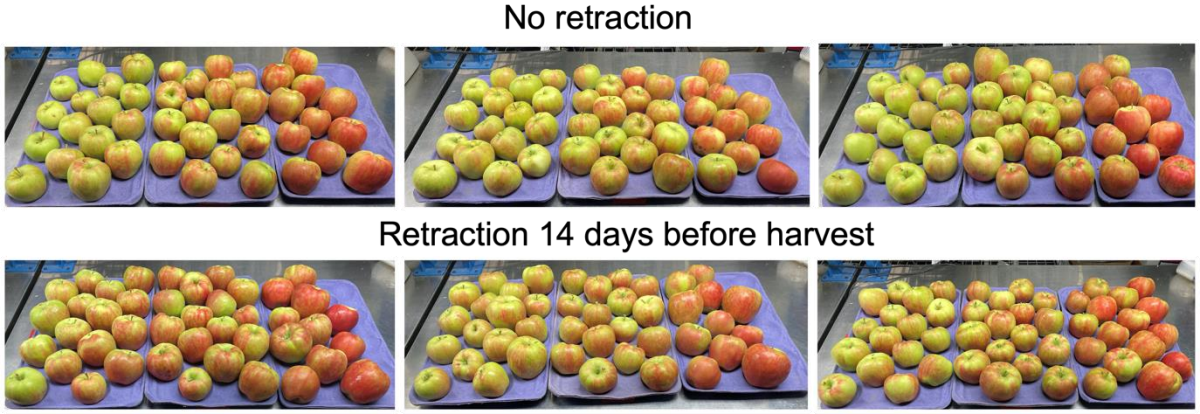

Figure 2. Fruit faced with sun-exposed portion of fruit in order from least colored (left) to most-colored (right) for Honeycrisp with either netting left in place until after harvest (top) or retracted 14 days before harvest (bottom).

Table 0. Fruit weight, red color coverage, and sunburn for netting treatments in 2022. P-values were found using ANOVA tests in RStudio at alpha=0.05.

Treatment	**Weight (g)**	**Red coverage %**	**Sunburn incidence %**	**SB1**	**SB2**	**SB3**	**SB4**
Retracted 14 days before harvest	265	17.3%	18.5%	9.3%	7.2%	2.1%	0.0%
Retracted 7 days before harvest	255	14.9%	18.3%	7.9%	6.3%	3.9%	0.2%
No retraction	269	14.2%	17.8%	6.3%	6.7%	3.5%	1.4%
P-value	0.2850	0.5558	0.9808	0.0154	0.8836	0.5277	0.0217

Table 4. Proportion of fruit belonging to five red color categories (0-20, 20-40, 40-60, 60-80, 80-100) for netting retracted 14 days before harvest, 7 days before harvest, or at harvest in 2021. P-values were found using ANOVA tests in RStudio at alpha=0.05.

Treatment	% 0-20 red	% 20-40 red	% 40-60 red	% 60-80 red	% 80-100 red
Retracted 14 days before harvest	9.0	13.6	27.5	33.4	16.7
Retracted 7 days before harvest	3.2	11.1	26.5	35.7	23.5
No retraction	13.3	16.7	25.4	25.8	18.8
P-value	0.1483	0.6208	0.7833	0.1472	0.4957

Table 5. Proportion of fruit belonging to five red color categories (0-20, 20-40, 40-60, 60-80, 80-100) for netting retracted 14 days before harvest, 7 days before harvest, or at harvest in 2022. P-values were found using ANOVA tests in RStudio at alpha=0.05.

Treatment	% 0-20 red	% 20-40 red	% 40-60 red	% 60-80 red	% 80-100 red
Retracted 14 days before harvest	68.8	16.2	9.3	4.2	1.6
Retracted 7 days before harvest	72.2	16.0	7.2	3.7	0.9
No retraction	75.2	11.8	7.4	3.9	1.6
P-value	0.5707	0.4219	0.5819	0.9725	0.5787

Retraction increased the proportion of fruit culled from sunburn, even in 2021 when sunburn pressure was lower during retraction (daily maximum temperatures were approximately 85 °F during this period) (Figure 4). In 2022, retraction was delayed until after September 5 to limit the risk of fruit sunburn in the commercial orchards as daytime maximum temperatures neared 100 °F. In 2021, 7% of fruit had severe sunburn whether it was retracted 7 days or 14 days before harvest. However, less than 4% of fruit had severe sunburn when netting was left in place until after harvest. Trends were similar in 2022 between treatments but sunburn incidence was lower. Between 4 and 5% of fruit was culled from sunburn for both retraction treatments compared to only 2% when netting was left in place until after harvest.

Experiment 2: Combining evaporative cooling and netting retraction at harvest

Table 6. Mean fruit weight, red color coverage, and sunburn of 'Honeycrisp' apple fruit with netting applied all season until harvest, netting applied all season and then retracted 10 days before harvest, or no netting used all season (Factor A) or with evaporative cooling (EC) or not (Factor B) in 2022.

Treatment	Fruit weight (g)	Red color coverage (%)	Sunburn incidence (%)	Sunburn rating (% fruit)			
				SB1	SB2	SB3	SB4
Factor *A*							
No retraction	244 a	12.5 a	13.7 a	8.4 a	4.2 a	0.2 a	0.9 a
Retracted	225 a	22.4 a	18.9 a	11.8 a	6.0 a	0.4 ab	0.8 a
No netting	236 a	18.3 a	24.9 a	12.4 a	7.5 a	3.2 b	1.8 a
p-value *A*	0.671	0.151	0.162	0.440	0.456	0.028	0.413
Factor *B*							
EC	232 A	17.6 A	15.8 A	9.1 A	4.7 A	0.8 A	1.2 A
No EC	238 A	17.9 A	22.5 A	12.7 A	7.1 A	1.7 A	1.1 A
p-value *B*	0.718	0.958	0.156	0.197	0.271	0.372	0.861
p-value *A* x *B*	0.600	0.643	0.386	0.361	0.866	0.310	0.194

Significant differences were determined using ANOVA tests performed in RStudio using the general linear model function. Letters indicate significant differences at $\alpha = 0.05$ according to a Tukey HSD test. Sunburn was rated on a scale of SB0-SB4 adapted for Honeycrisp from Schraeder et al. 2003 and shown in Willsea et al. 2023.

Since maturity was delayed in 2022 compared to 2021, the retraction period occurred 11 days later in 2022 (Table 2). However, the daily maximum temperature was approximately 8 °F greater in 2022 than 2021 during the retraction period. Fruit color development was poor, even in red Honeycrisp strains like Firestorm. Although color development was so poor, the mean starch rating was 3.5-4 for all fruit harvested at Sunrise and the background color was breaking from green to yellow indicating maturity of fruit on the tree. Delaying harvest longer would have resulted in excessive fruit drop and poor storability.

Table 7. Comparisons of the average red color coverage, retraction period, and average maximum temperature for 2021 and 2022.

	2021	2022
Average red color coverage (%)	58.3	17.7
Retraction period	August 18-August 30	August 29-September 8
Average daily maximum temperature during retraction (°F)	83.8	91.5

Unsurprisingly, uncovered fruit had the highest proportion of fruit with severe sunburn compared to netted fruit (Figure 5). Evaporative cooling only reduced the proportion of fruit with severe sunburn when it was used for uncovered or retracted trees. In 2021, when trees were left covered until after harvest, evaporative cooling did not significantly reduce the proportion of fruit with severe sunburn. We did not observe this same pattern in 2021. Looking at the main effects, evaporative cooling decreased losses from severe sunburn and netting, whether retracted or not, was effective at reducing severe sunburn. Interestingly, red color coverage (%) was improved when evaporative cooling was used in 2021 but while also higher in 2022, there was low statistical confidence in those differences. Overall, there were 10% more fruit with >33% red color coverage when EC was used in 2021 and 2.5% more fruit with >33% red color coverage when EC was used in 2022.

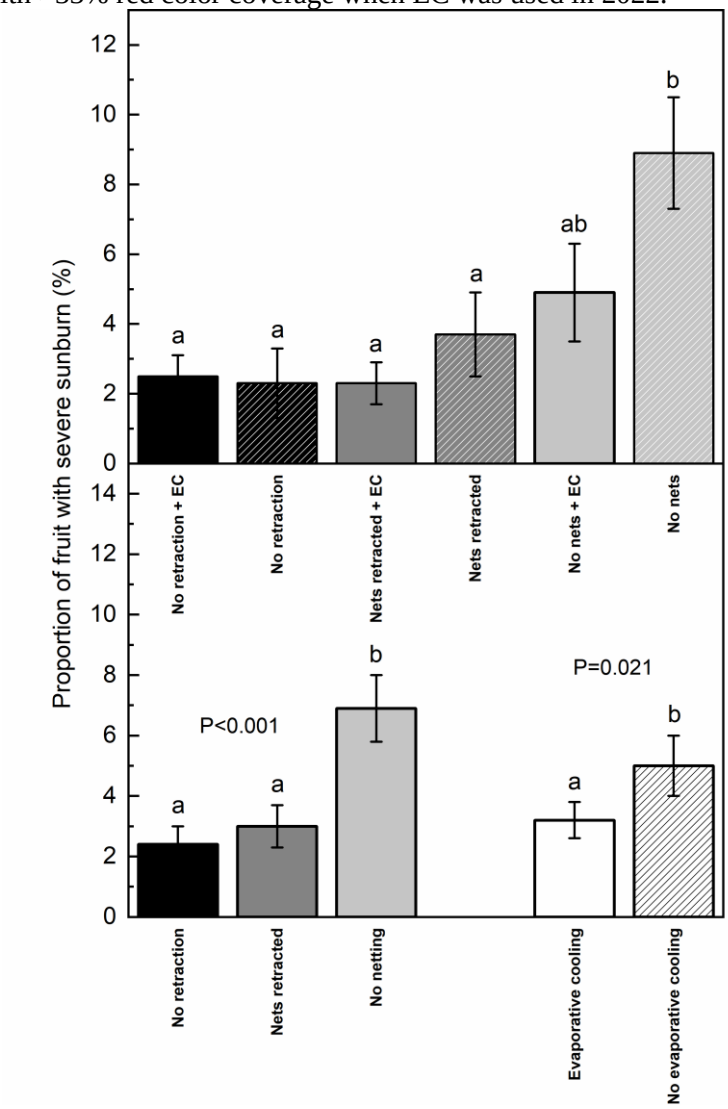

Figure 3. Mean proportions of total fruit (N=3) with sunburn exceeding SB2 based on the scale developed by Schrader et al. (2003), which would result in cullage in a commercial setting in 2021 and 2022 with no netting, netting deployed until harvest, or nets retracted 10 days before harvest and then either evaporative cooling (EC) or no EC applied. Letters indicate significant differences among means determined using a Tukey's HSD test ($\alpha = 0.05$).

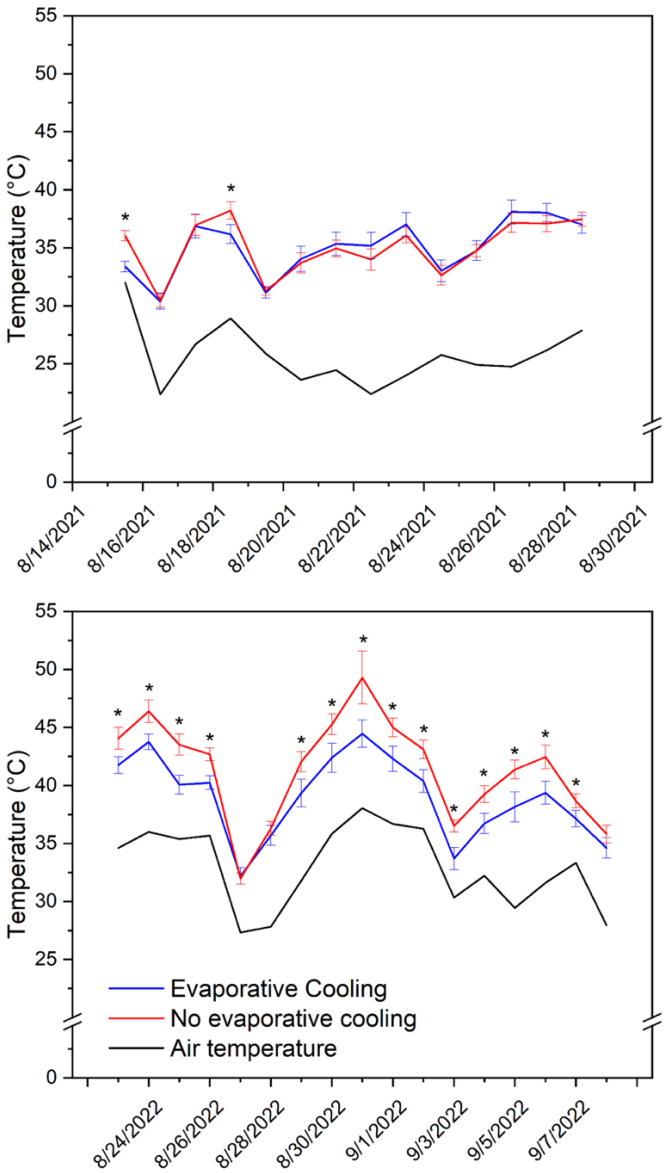

Figure 4. Average maximum daily temperature for the retraction periods in 2021 and 2022 for air temperature, treatments with evaporative cooling, and treatments without evaporative cooling. (N=3)

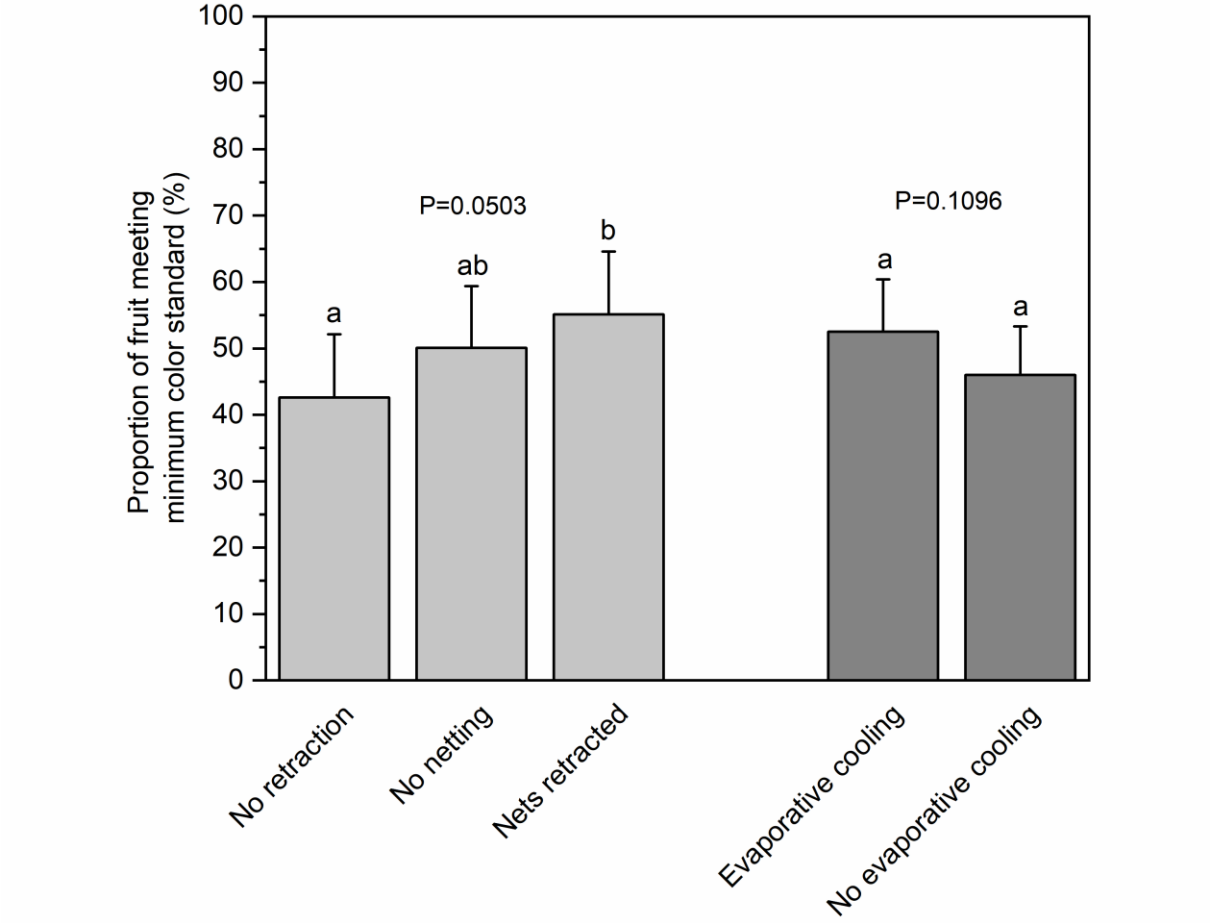

Figure 5. Mean proportions of 'Honeycrisp' fruit meeting Washington Extra Fancy standards for red color coverage thresholds for Honeycrisp apple in 2021 and 2022 with no netting, netting deployed until harvest, or nets retracted 10 days before harvest and then either evaporative cooling (EC) or no EC applied (N=3). Letters indicate significant differences among means determined using a Tukey's HSD test (alpha = 0.05).

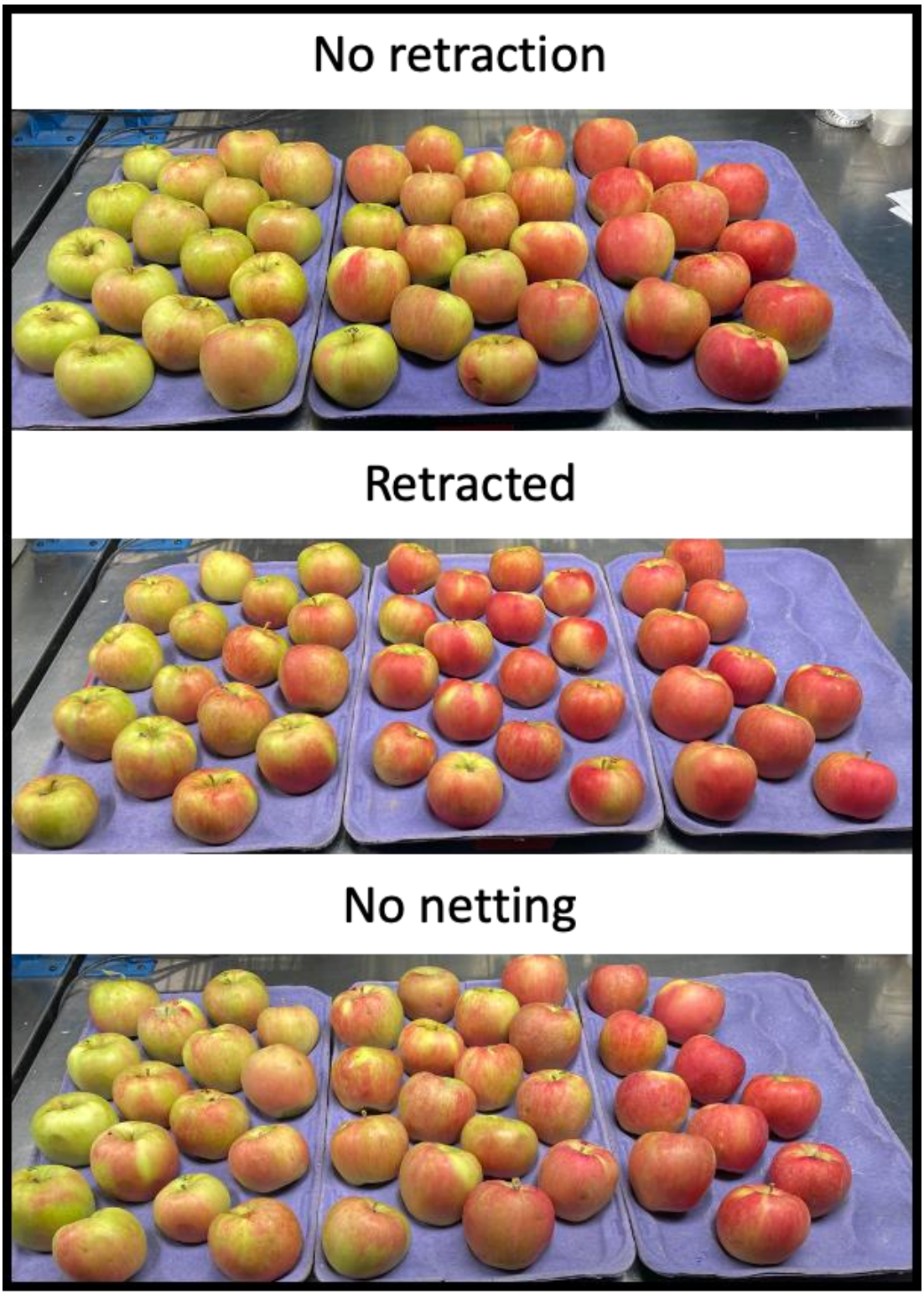

Figure 6. Representative Honeycrisp fruit samples from each netting treatment from the Sunrise research orchard in Rock Island, WA.

PROJECT OUTPUTS

Publications (open access)

Willsea N‡, Blanco V‡, Howe O‡, Campbell T‡, Kalcsits L. **2023**. Retractable netting and evaporative cooling to control sunburn and increase red color development in 'Honeycrisp' apple. HortScience, 58(11), 1341-1347.

Willsea N, Blanco V, Rajagopalan K, Campbell T, Howe O, Kalcsits L. **2023**. Reviewing the tradeoffs between sunburn mitigation and red color in apple under a changing climate. *Horticulturae*, *9*(4), 492

Presentations

Kalcsits L. **2022.** Tradeoffs between red color and sunburn in apple and management strategies to find this balance. Northwest Wholesale Annual Meeting. February 11, 2022.

Kalcsits L. **2021**. Physiology of Heat Stress and Mitigation Technologies. WSTFA Annual Meeting, Yakima, WA. December 7, 2021.

Lee Kalcsits and Noah Willsea. **2022**. Netting retraction focused discussion at monthly meeting for the Apple Horticulture and Protection metting. Yakima, WA. May 14, 2022.

Noah Willsea and Victor Blanco. **2022**. Heat impacts and management. Columbia Growers Club meeting. Pasco, WA. June 30, 2022.

Noah Willsea and Lee Kalcsits. **2022**. Netting retraction as a tool to improve red color in apple. American Society for Horticultural Sciences Annual Meeting. Chicago, Illinois. August 1, 2022.

Noah Willsea and Lee Kalcsits. **2022**. Netting Retraction to Improve Red Color in Apple. WSTFA Annual Meeting, Wenatchee, WA. December 7, 2022.

Willsea N, Kalcsits L. **2023.** Netting retraction to improve red color. Wenatchee Tree Fruit Days. January 19, 2023.

Kalcsits L. and Willsea N. **2023**. Fruit sunburn management. International Fruit Tree Association Annual Meeting. Grand Rapids, MI. February 15, 2023.

Kalcsits L. 2023. Heat mitigation. **2023** Virtual Meet Ups. July 23, 2023.

Extension publications

Sunburn in apple and strategies to mitigate it. **2021**. Jenny Bolivar-Medina and Lee Kalcsits. http://treefruit.wsu.edu/sunburn-in-apple-and-strategies-to-mitigate-it/

Cooling Mechanisms for a Tree Fruit Orchard. **2021.** Bolivar-Medina J, Kalcsits L. Fruit Matters July 2021. http://treefruit.wsu.edu/cooling-mechanisms-for-a-tree-fruit-orchard/

Netting retraction for enhancing red color development for Honeycrisp. **2024**. Lee Kalcsits, Victor Blanco, Noah Willsea. Nearing submission.

Executive Summary

Project title: Retraction of netting near harvest: risks vs. rewards

Key words: Netting, sunburn, red color, retraction

Abstract: Protective netting and evaporative cooling are commonly used in apple (*Malus domestica* Borkh.) orchards to protect apple fruit from sunburn in semi-arid environments like Central Washington. Sunburn is a physiological disorder caused by the combination of solar radiation and heat, which causes up to 10% or $100 million in yearly crop damages in Washington state. While protective netting and evaporative cooling can be effective for preventing apple sunburn, netting can also introduce new risks, especially the limitation of red color development on the apple peel. This study evaluated whether the retraction of netting before harvest improves red color development and/or changes sunburn risk compared to leaving netting in place until harvest. The first experiment compared six different treatments of 'Honeycrisp' apples in a research orchard consisting of combinations of netting either retracted ten days before harvest or not retracted and the presence or absence of evaporative cooling. The second experiment was performed on 'Honeycrisp' apples in a commercial orchard in Quincy, WA. Netting that had been in place during the growing season was removed fourteen days before harvest, seven days before harvest, or not at all. Fruit from both experiments were harvested and evaluated for sunburn incidence and external quality characteristics. Over the two years of experiments, netting reduced the levels of severe sunburn compared to the un-netted control. Meanwhile, the retraction of netting even up to 14 days before harvest did not increase sunburn risk in a younger orchard but in an older orchard with less vigor, sunburn was slightly greater when netting was retracted. Additionally, the retraction of netting before harvest increased the proportion of fruit with good and excellent red color. Overall, the use of retractable netting provided sunburn protection during the summer while avoiding red color penalties that come from netting deployed through harvest.