FINAL PROJECT REPORT

Project Title: Identification of procedures to extend 'Honeycrisp' storage life

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Other funding sources: CNPQ, Brazil (direct support to two graduate students)
Borlaug Foundation (direct support to one visiting scientist)

Total Project Funding: $210,142

WTFRC Collaborative expenses:

Item	**2013**	**2014**	**2015**
Wages	$8,000	$8,000	$8,000
RCA Room Rental	$630	$630	$630
Miscellaneous	$4,000[1]		
Total	$12,630	$8,630	$8,630

Footnotes: [1]Funds for acquisition of a differential absorbance (DA) meter for maturity assessment

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Item	**2013**	**2014**	**2015**	**2016**
Salaries	$39,586	$39,586	$39,586	
Benefits	$19,498	$19,498	$19,498	
Supplies	$1,000	$1,000	$1,000	
Total	$60,084	$60,084	$60,084	$0

Footnotes: No cost extension for 2016.

OBJECTIVES

1. Characterize differences in orchards that produce fruit with a history of disorder resistance or susceptibility.
2. Determine utility of ethylene green life, fruit density, titratable acidity, chlorophyll fluorescence and chlorophyll absorbance as additional indicators of storability.
3. Identify alternatives to the 7 day 50 ^{o}F pre-conditioning protocol.
4. Identify factors contributing to CO_2 injury occurring during the initial 30 days after harvest.
5. Identify CA protocols that maximize quality retention and minimize disorders.

SIGNIFICANT FINDINGS

Objective 1: Fruit from middle and low positions in v-trellis canopies displayed higher sensitivity to chilling injury in storage. Fruit position within the canopy influenced at harvest fruit quality to a greater extent than netting (except sunburn development). Netting of orchards led to changes in fruit quality after storage, most notably less bitter pit developed.

Objective 2: Ethylene green life varies with maturity at harvest and orchard lot. Fruit chlorophyll fluorescence changes during cooling but is not an indicator of chilling sensitivity. Fruit with high titratable acidity (TA) at harvest have relatively high TA after storage. The DA meter was able to track fruit maturation before picking, but did not correlate closely to other maturity indicators and did not pick up chilling injury development in storage. Dry matter is poorly correlated with soluble solids content or other quality and disorder indicators at harvest and after storage.

Objective 3: Conditioning less than 7 days can enhance chilling injury. Humidity during conditioning does not influence chilling disorder development.

Objective 4: High CO_2 during 1-MCP treatment the day of or after harvest does not cause CO_2 injury.

Objective 5: Bitter pit incidence can be reduced by CA and 1-MCP. Incidence is reduced the most by 1-MCP treatment the day of harvest followed by CA establishment the following day while fruit is at 50 ^{o}F. Total non-chilling disorder incidence is not enhanced by CA during conditioning.

RESULTS & DISCUSSION

1. Orchard factors: Fruit position in tree & light environment: Disorder incidence in storage was highly correlated by harvest sequence and location of fruit within the tree in all three years of the study. In particular, *soft scald* disorder sensitivity increased with advance in harvest date for fruit grown in the middle and lower parts of the canopy, while fruit grown in top parts of the canopy exhibited soft scald, at times beginning with the second pick, but at much lower overall levels (Figure 1). Generally the first symptoms were observed after four weeks of forced cooling (chilling temperatures of 33°F), preferentially in lower parts of the canopy (example in Figure 2). Netting delayed the onset of soft scald, diminished the total amount expressed over time and evened out the canopy effect, i.e. symptoms expressed throughout canopy. (Fig. 1&2)

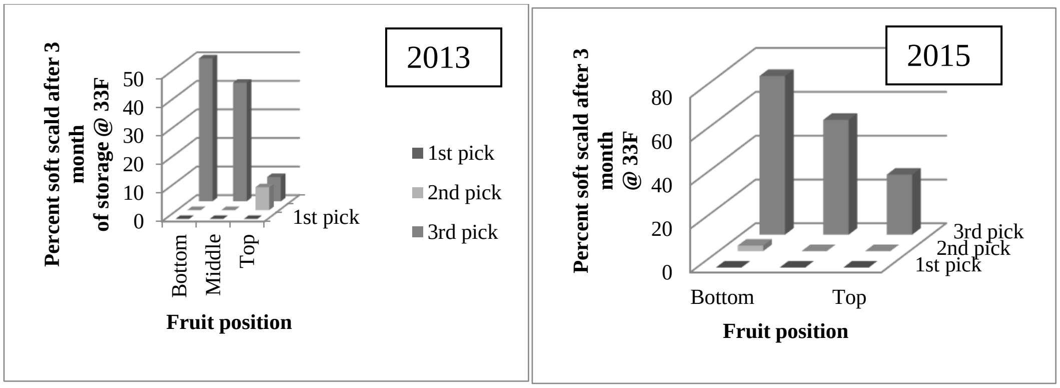

Figure 1: Development of soft scald in Honeycrisp apples stored for 12 weeks at 33°F. Fruit was harvested in 3 picks from three canopy positions from 2013 and 2015.

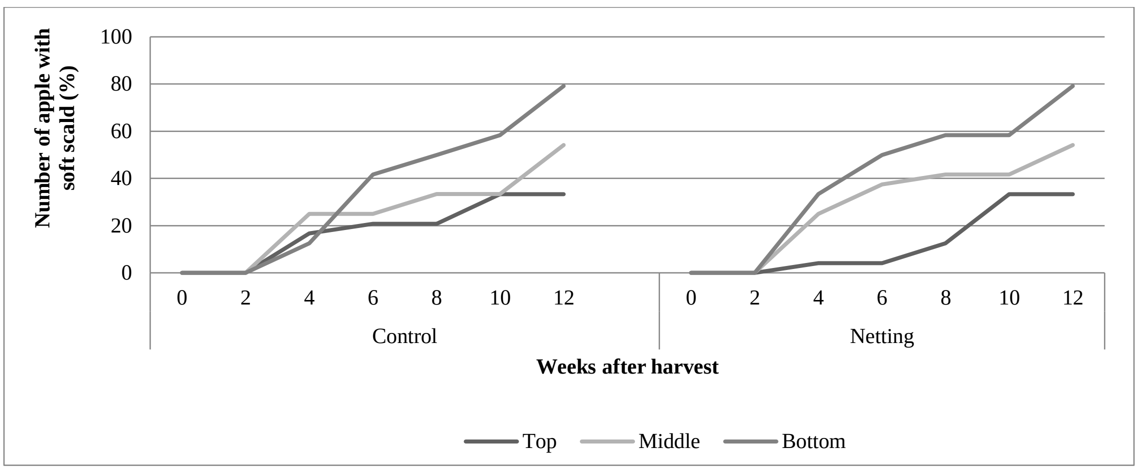

Figure 2: Time course of soft scald development in Honeycrisp apples stored for 12 weeks at 33°F in 2015. (Orchard 2, 3rd pick)

When storing fruit from netted and un-netted sections of Honeycrisp orchards, with or without 1-MCP application prior to CA establishment, we also found a marked *reduction of bitter pit* symptom expression in fruit grown under the 20% shade net, regardless of orchard or postharvest treatment (example in Figure 3).

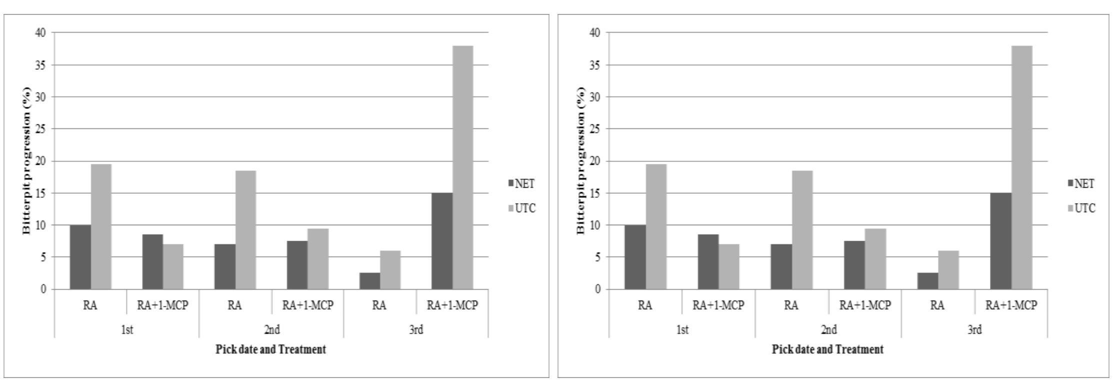

Figure 3: Bitter pit expression of Honeycrisp apples after three months of cold storage; fruit grown in two orchards near Gleed, WA in 2014 with and without shade netting

We utilized the DA meter in all three years of the study to determine it's utility to track maturity development, assess potential correlations to other common maturity indicators and non-destructively track fruit in forced chilling conditions to determine the DA meters capacity to detect chilling stress before visual symptoms appear on the fruit surface. As fruit matured on the tree, DA meter values decreased (as expected) and at harvest we typically observed a range of 1.2-0.5, depending on fruit position within tree (lower values in higher canopy positions). (Table 1) Fruit grown in the top section of the canopy was generally redder, sweeter and more acidic (2015 example in Table 1), while starch degradation rates, background color change, fruit size, and DA meter values appeared to be more independent of position of fruit within the canopy. Netting sometimes affected single maturity parameters depending on orchard location and year, but most often, fruit from netted sections expressed maturity similar to fruit from unnetted sections (Example in Table 1). Examples of effects of netting on at harvest maturity form 2014 include: the lone maturity parameter affected by netting was higher colored fruit in the upper netted section as compared to the lowest untreated section in the first pick (2014); netted fruit had lower sugar concentration (2nd and 3rd pick) and higher DA meter values (2nd pick) (data not shown).

Table 1: Selected at harvest quality parameters for fruit from the third pick of two orchards near Gleed, WA partially covered by netting in 2015.

Parameter	**Location 1**		**Location 2**	
	Control	**Netting**	**Control**	**Netting**
Diameter (inch)	3.3	3.4	2.9	3.0
Color (1-4)	3.8	3.7	2.9	2.8
Firmness (lbs.)	13.4	12.7	14.6	14.7
SSC (%)	13.3	13.1	13.3	13.3
TA (%)	0.377	0.397	0.473	0.529
Starch (1-6)	4.7	4.6	5.0	4.8

Netting of orchards consistently influenced the amount and severity of sunburn at harvest for all three years of the experiment (2015 example in Figure 4), thus significantly increasing the amount of packable fruit at harvest.

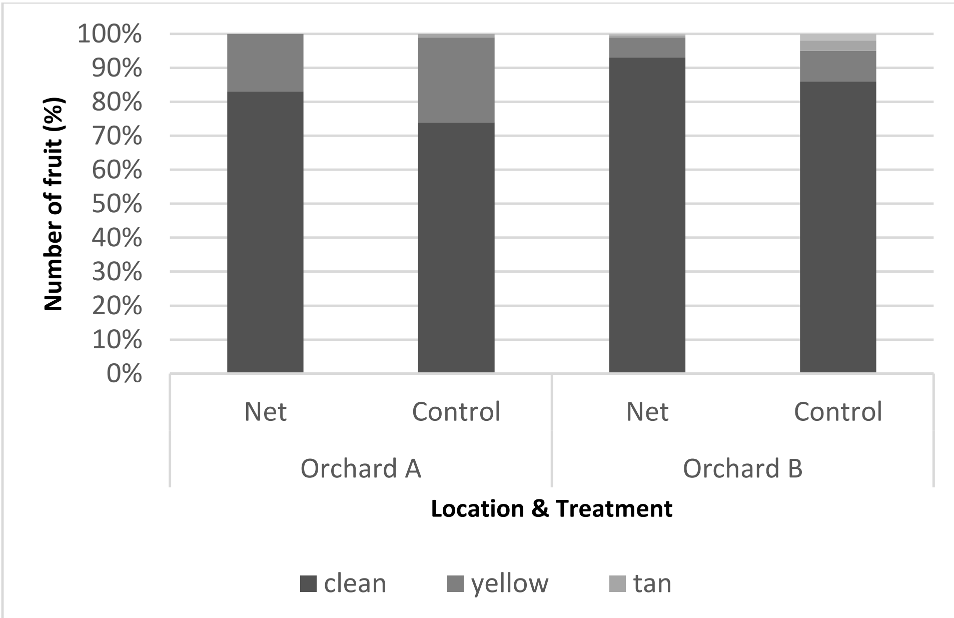

Figure 4: Sunburn incidence and severity in two Honeycrisp orchards at harvest in 2015.

2. Harvest and postharvest factors. Correlations among maturity and quality indicators at-harvest and at-harvest and after storage were evaluated particularly for dry matter and soluble solids content. Correlations were low for dry matter and soluble solids content at harvest and after 4 months air storage (Figure 5), however, a high correlation existed for soluble solids content at harvest and after storage. Results are for the first year of this comparison, additional results will be presented with the final oral report. Notable in the dry matter – SSC comparison are the low SSC/high dry matter values for late harvest, poor quality fruit. Harvest typically with most starch hydrolyzed may be a contributing factor to the relationships observed.

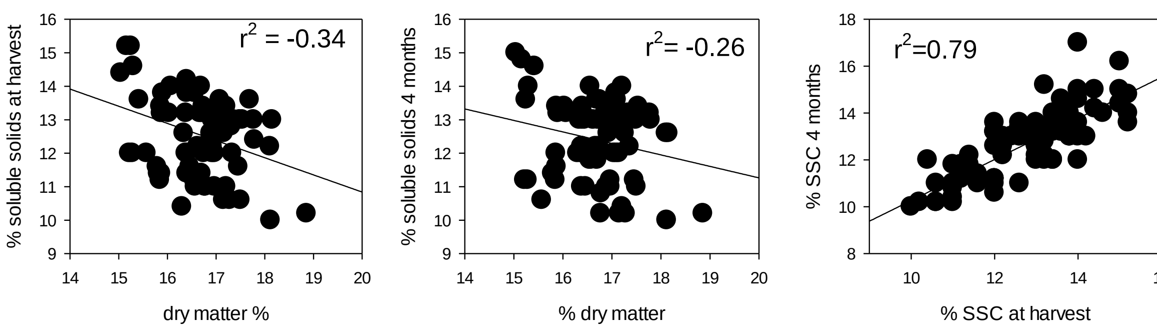

Figure 5. Relationship between fruit dry matter and soluble solids content at harvest and after storage. Fruit were stored 4 months in air then 7 days at 70 °F.

Initial ethylene production and rate of production increase may be indicators of storability. Lower ethylene production is associated with earlier harvest but the production increase during a week at 70 °F is not always reflective of initial values (Fuller harvests 1 and 2; Figure 6). Lower ethylene production is often associated with lower respiration rate and reduced utilization of titratable acidity, slower yellowing and greasiness development.

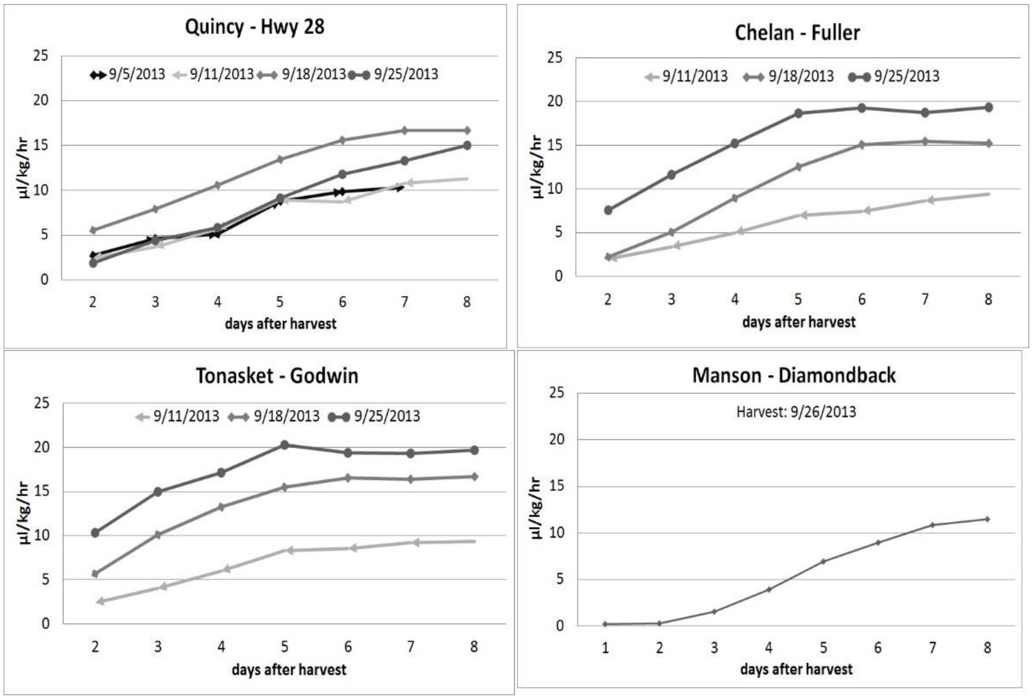

Figure 6. Ethylene production during 8 days at 70 ºF following harvest.

Cold room humidity had no effect on subsequent development of chilling disorders (Figure 7). Fruit not conditioned but cooled to 37 ºF in 40 or 85% relative humidity developed similar amounts of soft scald.

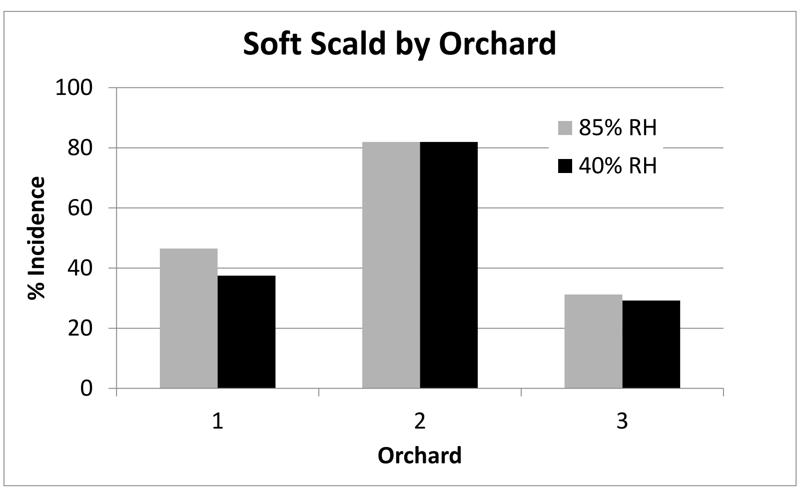

Figure 7. ‘Honeycrisp’ soft scald following 4 months cold storage in air.

The lack of difference in chilling sensitivity was in contrast to a difference in fruit chlorophyll fluorescence during cooling in the two relative humidities (Figure 8). The results indicate the hypothesis that water loss as provoked by low humidity during cooling can impact fruit chilling sensitivity appears to be invalid.

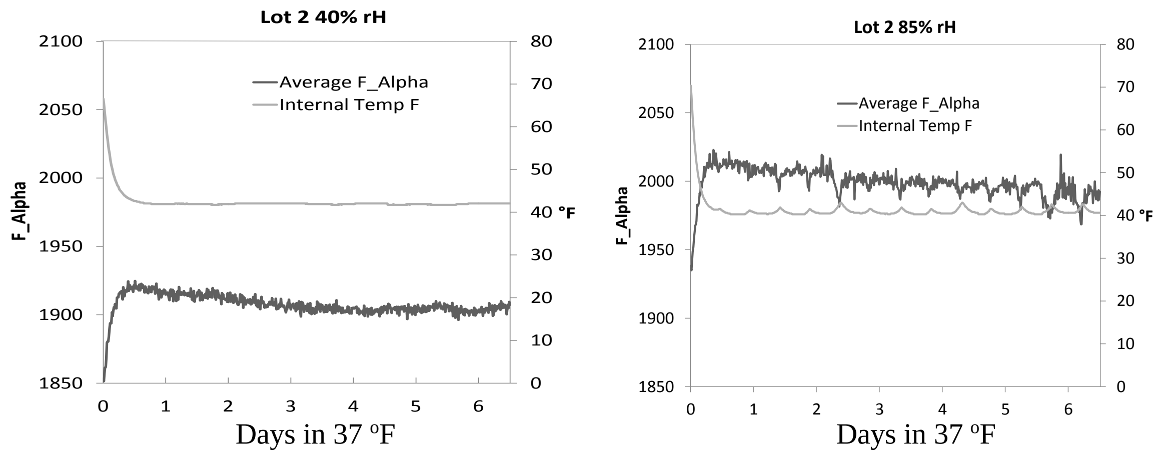

Figure 8. Honeycrisp chlorophyll fluorescence during cooling to 37 °F.

No relationship was observed between chlorophyll fluorescence at the initiation of chilling and subsequent development of soft scald or bitter pit (Figure 9).

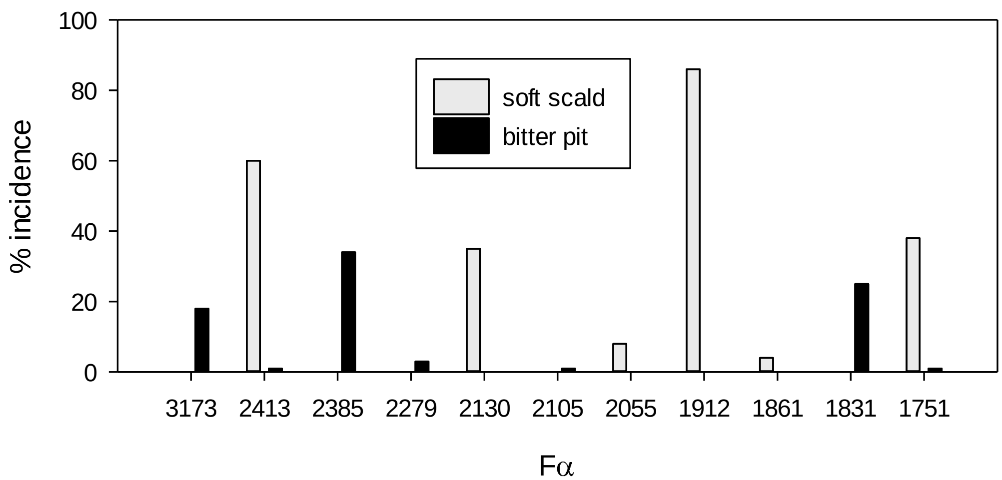

Figure 9. 'Honeycrisp' chlorophyll fluorescence Fα at harvest and soft scald and bitter pit development after storage at 33 °F in air for 3 months.

Managing conditioning rooms loaded over an extended period is a logistical challenge to meet the 7 day conditioning recommendation. We found that reducing the conditioning temperature by 5 °F after 2 and 4 days and then 3 °F at 7 days enhanced chilling injury (Figure 10). The results indicate risk of chilling injury can be enhanced by altering the conditioning protocol in this step down fashion. Additional research could be conducted to examine less rapid cooling during conditioning.

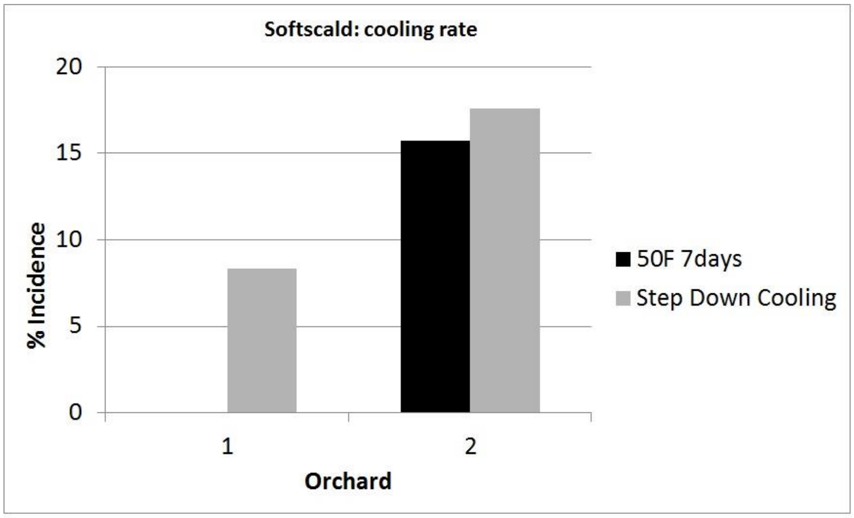

Figure 10. Soft scald incidence after 4 months cold storage in air.

Risk of CO_2 injury resulting from a 24 hour exposure resulting from CO_2 accumulating during 1-MCP treatment after harvest was examined over two years in three orchards. Fruit were conditioned for 7 days then held in air for 4 months. In no instance was a relationship observed between 1-MCP treatment and CO_2 injury in chambers where up to 4% CO_2 was present during 1-MCP treatment (Table 2). Untreated fruit did not develop high amounts of CO_2 injury either. The results indicate a negligible risk for fruit CO_2 injury resulting from a 24 hour exposure within a day of harvest. As the risk of CO_2 injury decreases the longer fruit have been in storage, the results suggest a concern for CO_2 exposure should not limit the timing of 1-MCP treatment after harvest.

	% CO_2	% cortex browning	
Orchard	initial	Control	1-MCP
A	0.0	0 (2.1)*	0 (1.9)
	2.0	0 (3.8)	0 (3.7)
	4.0	0 (4.8)	0 (5.2)
B	0.0	0 (2.6)	0 (2.4)
	2.0	0 (4.5)	0 (4.5)
	4.0	0 (5.1)	0 (5.8)
C	0.0	0 (2.1)	0 (2.0)
	2.0	2 (3.8)	0 (3.7)
	4.0	2 (5.1)	0 (5.5)

Table 2. Honeycrisp CO_2 injury incidence following 24 hour CO_2 exposure after harvest. Fruit were stored in air for 4 months plus 7 days at 70 ^{o}F.

Procedures to definitively establish orchard susceptibility to bitter pit remain unknown. As CA storage is known to reduce bitter pit development for other apple varieties, assessment of CA with and without the use of 1-MCP was assessed including initiation of CA during conditioning. In three years with 2 or 3 lots per year, both CA and 1-MCP were shown to reduce bitter pit development compared to untreated fruit stored in air (Figure 10). The best bitter pit reduction resulted from 1-MCP treatment the day fruit was received with CA established the following day. No evidence of enhanced incidence of other disorders due to CA during conditioning was observed. Some evidence of enhanced titratable acidity after storage was apparent from the 1-MCP/rapid CA treatment. The lack of damage from the rapid CA protocol used (3% O_2, 0.5% CO_2 after 1 day, 2% O_2, 0.5% CO_2 after 5 days) suggests additional research is needed to identify conditions where rapid CA establishment can cause fruit injury.

Atmosphere 1-MCP	Bitter Pit %	Peel Blotch %	Diffuse Browning %	Cavity %	Total non-chilling %	Soft Scald %	Soggy Breakdown %	Titratable Acidity %
Control: CA9d CA 1d air 1-MCP: CA 9d CA 1d air	26a 15bc 30a 18bc 10c 23ab	0.9b 2b 0b 9a 7a 15a	3.0 0.9 1.6 1.7 1.6 0.7	5.1a 2.1b 0.6b 5.3a 4.7a 2.0b	31a 17b 30a 23ab 15b 24ab	2.3 2.0 1.3 4.0 2.3 2.1	3.3 2.1 0.4 2.9 3.1 0.9	0.387a 0.409a 0.294b 0.415a 0.445a 0.372ab

Table 3. “Honeycrisp’ disorders and titratable acidity after 7 months storage 7 days at 70 °F. Summary of 7orchard years (2 years 2 lots per year, 1 year 3 lots). CA: 3% O_2 2 days, then 2% O_2, 0.5% CO_2 throughout. All fruit held 7 days at 50 °F, then at 37 °F. Means followed by different letters are significantly different, $p \leq 0.05$.

EXECUTIVE SUMMARY

Identification of orchard and postharvest factors that influence 'Honeycrisp' quality and disorder susceptibility provides information to enhance grower returns. Information developed in this project suggests pre- and post-harvest techniques that may reduce losses and enhance fruit quality. These include tree canopy management to reduce fruit numbers inside the canopy that tend to be highly susceptible to chilling injury. These fruit typically also are poorly colored and have low quality due to poor ripening and low soluble solids content. Reducing direct sunlight by netting also resulted in less bitter pit development while minimally impacting fruit quality attributes. Further research to more clearly define light environment impacts on fruit quality and postharvest disorders may provide additional benefits for field management.

Harvest and postharvest technologies continue to become available that assess additional components of fruit physiology and quality. The differential absorbance (DA) meter measures chlorophyll activity and changes in DA values have been related to fruit maturation. While the maturation tracking was confirmed for 'Honeycrisp', DA values did not correlate well with other indicators of maturity and quality. This may be due to a lack of physiological connection between chlorophyll metabolism and other aspects of fruit maturation that contribute to quality. Orchard as well as in-orchard variability also may compound the use of DA technology. However, individual growers may find utility for this instrument with repeated use over years and blocks that may enhance or confirm knowledge of fruit physiological progression in specific areas. Chlorophyll fluorescence (CF) is another property for which relatively new technology is available. This technology has been typically applied for use to establish CA oxygen content, and we found while CF values vary with fruit lots during cooling in air and in low and high humidity, utility of the CF values as a predictor for chilling injury was not established. Continued research evaluating CF as a tool during CA establishment during conditioning is warranted. Ethylene production during the immediate postharvest period can provide a means to indicate lot specific production patterns, however, utility of this information as an indicator of storage performance remains to be established. Technologies that reduce ethylene production and response (CA, 1-MCP) have been demonstrated to effectively extend Honeycrisp storage life. Conditioning to reduce chilling injury remains a necessary protocol in the absence of a means to identify lot susceptibility to low temperature. This protocol can enhance bitter pit development, and our results showing CA established during conditioning provide a means to reduce this disorder. Further work to define the optimal CA environment as well as CA conditions under which injury occurs would enhance the utility of this protocol as well as define the risk of rapid CA for Honeycrisp.

The continued profitability of Honeycrisp due in part to apparent lessening of chilling disorder risk due to adoption of conditioning throughout the industry is an example of research contributing to industry success. This project's results expand the knowledge of Honeycrisp produced under PNW conditions and may further enhance Honeycrisp management. The project participants thank the WTFRC for the opportunity to conduct these studies and look forward to continued work in this research area.