MSU CA Clinic: 2014

Michigan State University

A publication of the MSU FRUIT TEAM

Controlled Atmosphere Storage and Warehousing Clinic
Clarksville Horticulture Experiment Station
Boulder Creek Golf Club, Belmont, MI
August 6, 2014

Volume 8

R.M. Beaudry, Heidi Davey and Ken Silsby, Organizers

Department of Horticulture

Pace International LLC

DECCO

VALENT

SCS INC STORAGE CONTROL SYSTEMS

AgroFresh

DOW

Dow AgroSciences

MSU CONTROLLED-ATMOSPHERE AND STORAGE CLINIC

TABLE OF CONTENTS

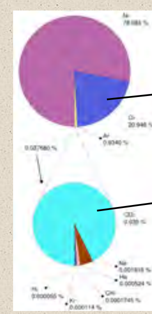
Volume 8

2014 TOPICS **Page**

CO_2 injury in apples: an introduction

R.M. Beaudry
Michigan State University

Typical Atmosphere Composition



The Roman, Varro, of the 1st century B.C. provides us with the first written evidence for modified atmospheres:

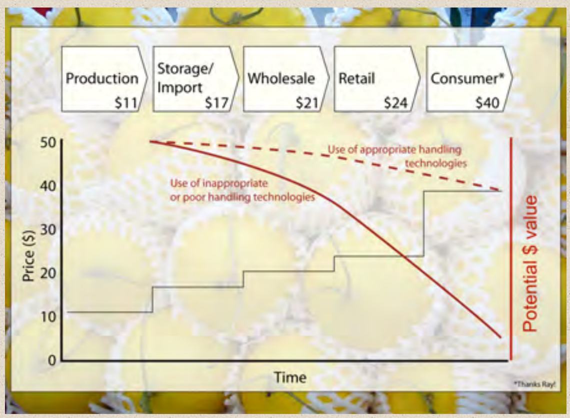
"..getting into [the silos] is attended with danger, when they are first opened, on account of the confined air..."

-translation by T. Owen, 1800

The Romans built sealed silos for grain storage

Landmarks in CA discovery and development

100 BC	Romans use sealed underground pits
1821	J. Berard links respiratory gases with the biology of harvested fruits
1869	Benjamin Nyce builds first CA storage in Ohio
1914	Kidd and West observe the impact of elevated CO_2 and reduced O_2 on plant metabolism
1927	Kidd and West describe the influence of elevated CO_2 and reduced O2 on fruit ripening
1929	CA storage becomes a commercial success in England



O_2 and CO_2 levels linked in CA rooms

Respiration, even at low O_2, yields approximately 1 CO_2 molecule per O_2 consumed.

The tendency for CA rooms is to ‘equilibrate’ with the outside air such that the O2 and CO2 levels add to ~21%

Therefore CO_2 will always want to accumulate when held at typical CA concentrations of 1 to 3%.

Biological basis of CO_2 effects

- mild stress concentrations of CO_2 used in CA environments
  - reduce respiration rate
  - inhibits ethylene production and action
  - retard compositional changes
  - alleviate some physiological disorders
  - retard decay development
- optimum concentrations of CO_2 used in CA environments
  - retard loss of chlorophyll, biosynthesis of carotenoids and anthocyanins
  - slows down the activity of cell wall degrading enzymes
  - reducing loss of acidity, starch to sugar conversion, interconversion of sugars, biosynthesis of flavor volatiles
  - retain ascorbic acid and other vitamins

Biological basis of CO_2 effects (cont.)

- Post climacteric fruits are less tolerant and have lower capacity for recovery following exposure to reduced O_2 and / or elevated CO_2 levels
- Specific concentrations of O_2 and CO_2 vary among commodities, cultivars, maturity, ripeness stages storage temperatures, duration of storage (and ethylene levels)

Commercially valuable physiological responses of modified atmospheres

Gas	Range (kPa)	Response	Commodities
CO_2	1 - 5	Reduced ethylene perception	Apple, banana, kiwifruit, cabbage
	3 - 15	Reduced chlorophyll degradation	Apple, banana, kiwifruit, cabbage, broccoli, asparagus
	5 - 20	Suppressed decay (fungal sporulation and/or growth)	Blueberry, blackberry, cherry, raspberry, strawberry, onion

Regarding atmosphere modification:

Atmosphere modification is not always appropriate

The primary benefit of CA/MAP is through
- ethylene action
- decay prevention
- browning inhibition
- *some* benefits to respiratory suppression

It is as important to know the limits of a tissue as it is to know the potential benefits

...and re-DPA...

efsa

European Food Safety Authority

EFSA Journal 2012;10(1):2486

CONCLUSION ON PESTICIDE PEER REVIEW

Conclusion on the peer review of the pesticide risk assessment of the active substance diphenylamine[1]

European Food Safety Authority[2]

European Food Safety Authority (EFSA), Parma, Italy

Following the Commission Decision of 30 November 2009 (2009/859/EC)[3] concerning the non-inclusion of diphenylamine in Annex I to Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing that substance, the applicant, the European Diphenylamine Task Force made a resubmission application for the inclusion of diphenylamine in Annex I in accordance with the provisions laid down in Chapter III of Commission Regulation (EC) No. 33/2008. The resubmission dossier included further data in response to the issues identified in the conclusions leading to the Decision on non-inclusion, as set out in the Review Report (SANCO/191/08) as follows:

The information available is insufficient to satisfy the requirements set out in Annex II and Annex III Directive 91/414/EEC in particular with regard to:

the risk to consumers.

CONCLUSION ON PESTICIDE PEER REVIEW

Conclusion on the peer review of the pesticide risk assessment of the active substance diphenylamine[1]

European Food Safety Authority[2]

European Food Safety Authority (EFSA), Parma, Italy

SUMMARY

Diphenylamine is one of the 84 substances of the third stage Part B of the review programme covered by Commission Regulation (EC) No 1490/2002[3] as amended by Commission Regulation (EC) No 1095/2007.[4] This Regulation requires the European Food Safety Authority (EFSA) upon request of the European Commission to organise a peer review of the initial evaluation, i.e. the Draft Assessment Report (DAR), provided by the designated rapporteur Member State and to provide within 6 months a conclusion on the risk assessment to the European Commission.

Ireland being the designated rapporteur Member State submitted the DAR on diphenylamine in accordance with the provisions of Article 10(1) of the Regulation (EC) No 1490/2002, which was received by the EFSA on 20 June 2007. The peer review was initiated on 8 October 2007 by dispatching the DAR for consultation of the Member States and the applicants Cerexagri s.a. and Pace International. Subsequently, the comments received on the DAR were examined and responded by the rapporteur Member State in the reporting table. This table was evaluated by EFSA to identify the remaining issues. The identified issues as well as further information made available by the applicant upon request were evaluated in a series of scientific meetings with Member State experts in May - June 2008.

A final discussion of the outcome of the consultation of experts took place during a written procedure with the Member States in September 2008 leading to the conclusions set out in the EFSA Conclusion issued on 30 September 2008 in the EFSA Scientific Report (2008) 188.

Following the Commission Decision of 30 November 2009 (2009/859/EC)[5] concerning the non-inclusion of diphenylamine in Annex I to Directive 91/414/EEC and the withdrawal of authorisations for plant protection products containing that substance, the applicant, the European Diphenylamine Task Force made a resubmission application for the inclusion of diphenylamine in Annex I in accordance with the provisions laid down in Chapter III of Commission Regulation (EC) No. 33/2008. The resubmission dossier included further data in response to the issues identified in the conclusions leading to the Decision on non-inclusion, as set out in the Review Report (SANCO/191/08) as follows:

> The information available is insufficient to satisfy the requirements set out in Annex II and Annex III Directive 91/414/EEC in particular with regard to:
>
> - the risk to consumers.

[1] On request from the European Commission, Question No EFSA-Q-2011-00232, approved on 2 December 2011.
[2] Correspondence: pesticides.peerreview@efsa.europa.eu
[3] OJ No L 224, 21.08.2002, p. 25, as amended by Regulation (EC) No 1095/2007 (OJ L 246, 21.9.2007, p. 19)
[4] OJ L 246, 21.9.2007, p. 19
[5] OJ L 314, 1.12.2009, p. 79

Suggested citation: European Food Safety Authority; Conclusion on the peer review of the pesticide risk assessment of the active substance diphenylamine. EFSA Journal 2012;10(1):2486. [59 pp.]. doi:10.2903/j.efsa.2012.2486. Available online: www.efsa.europa/efsajournal.htm

And concerns were identified with regard to

- the lack of data on the levels and toxicity of unidentified metabolites of the substance;
- the possible formation of nitrosamines during storage of the active substance and during processing of treated apples;
- the lack of data on the potential breakdown or reaction product of diphenylamine residues in processed commodities;
- the lack of data to finalise the specification.

In accordance with Article 18 of Commission Regulation (EC) No. 33/2008, Ireland, being the designated RMS, submitted an evaluation of the additional data in the format of an Additional Report. The Additional Report was received by the EFSA on 3 December 2010.

In accordance with Article 19 of Commission Regulation (EC) No. 33/2008, the EFSA distributed the Additional Report to Member States on 13 December 2010 and the applicant on 11 January 2011, for comments. The EFSA collated and forwarded all comments received to the European Commission on 24 February 2011.

In accordance with Article 20, following consideration of the Additional Report and the comments received, the European Commission requested the EFSA to deliver its conclusions on diphenylamine.

The conclusion from the original review was reached on the basis of the evaluation of the representative use as a plant growth regulator as proposed by the applicant. It is applied as a post-harvest drench to apples before they go into storage. The conclusion of the peer review of the resubmission was reached on the basis of the evaluation of the same representative use. Full details of the representative use can be found in Appendix A.

The representative formulated product for the evaluation was "No Scald DPA 31", an emulsifiable concentrate (EC).

Adequate methods are available to monitor all compounds given in the respective residue definition, except for surface water and products of animal origin. Residues in food of plant origin can be determined with a multi-method (the German S19 method has been validated). For the other matrices only single methods are available to determine residues of diphenylamine. A data gap is identified for a method of analysis for products of animal origin and for surface water.

Sufficient analytical methods as well as methods and data relating to physical, chemical and technical properties are available to ensure that quality control measurements of the plant protection product are possible.

In the mammalian metabolism studies, diphenylamine was rapidly and completely absorbed after oral administration, it underwent extensive metabolism to sulphonyl and glucuronyl conjugates and was rapidly excreted mainly via urine. Acute oral and dermal toxicity were low; it was not technically feasible to perform an acute toxicity study by inhalation. Diphenylamine was not a skin irritant, but can cause severe irritation to the eyes; therefore, classification with **Xi "irritant"** and risk phrase **R41 "risk of serious damage to eyes"** was proposed. According to a Magnusson and Kligman test, diphenylamine was not a skin sensitizer.

The red blood system was the target organ of diphenylamine in rats, mice and dogs, upon short-term and long-term exposure, as evidenced by altered haematological parameters, splenic erythropoiesis, splenic congestion and haemosiderosis. Additionally, histopathological changes in the liver and kidneys were found upon longer exposure. The relevant short-term NOAEL of 9.6 - 10 mg/kg bw/day was derived from the 90-day rat, 90-day dog and 1-year dog studies. The relevant long-term NOAEL was the dose level of 7.5 mg/kg bw/day from the 2-year rat study.

No genotoxic potential was attributed to diphenylamine; no carcinogenicity was observed in either rats or mice. Reproductive effects were limited to reduced implantation sites in F_1 females associated with reduced litter size at clear parental toxic doses (reduced food intake/body weight gain and haemolytic condition). No effect on development was attributed to diphenylamine administration in rat or rabbit.

No neurotoxic alert was evident in the data package provided.

The Acceptable Daily Intake (ADI) of diphenylamine was 0.075 mg/kg bw/day based on the 2-year rat study, applying a safety factor of 100; the Acceptable Operator Exposure Level (AOEL) was 0.1 mg/kg bw/day based on the 90-day rat, 90-day and 1-year dog studies, and applying a safety factor of 100; no Acute Reference Dose (ARfD) was allocated. As no study was provided, default dermal absorption value of 100% was assumed for risk assessment. The level of operator exposure calculated for the representative formulation "No Scald DPA 31" was below the AOEL according to the mixing and loading phase of the German model when operators wear gloves. Considering the very specific indoor use of diphenylamine, bystander and re-entry worker exposure were not considered relevant. The worker exposure (interpreted as sorting out and packaging fruits activities) risk assessment relates to the automated handling of the treated fruits; manual handling of the fruits has not been taken into consideration.

The metabolism of diphenylamine was investigated in apples at different time intervals after a post-harvest treatment by dipping. Over the course of the study a penetration of the radiolabelled residues was observed from the surface of the fruit into the pulp. Upon analysis diphenylamine was always the major residue, however identification of metabolites was considered insufficient by the meeting of experts and therefore a data gap was set to address the identity of the metabolites coded 1, 2 and 3 detected in significant amounts in the apple samples. Also the potential for presence or formation of nitrosamines in apple metabolism or during processing is not excluded and has to be investigated according to a fully validated analytical method. This data gap is linked to the data gap set to address the nature of the residues in the apple processed commodities. The residue definition for monitoring was set as diphenylamine alone whilst the residue definition for risk assessment could only provisionally be proposed as the parent compound, pending the outcome of the additional data to address the identity of the metabolites 1, 2 and 3 and also the potential presence of nitrosamines both in apple extracts and in processed commodities.

Livestock metabolism and feeding studies in ruminants were evaluated and considered as acceptable. The applicant made a case that treated apples are destined only for direct human consumption and will not be part of livestock diet. However, since any restriction with respect to the use of treated apples or commodities derived from treated apples in animal feeding is not in the remit of the risk assessor, a "worst case" assessment has to be carried out assuming livestock exposure to diphenylamine residues from treated apples in order to derive MRLs for animal matrices. The residue definition for monitoring was set as diphenlyamine alone, while for risk assessment EFSA proposed to include both diphenylamine and the conjugates of 4-hydroxy diphenylamine since these metabolites were found to be predominant in milk. The residue definition for risk assessment has to be regarded as provisional pending the outcome of the additional data on the nature and magnitude of the residues in apple wet and dry pomace and the recalculation of the livestock dietary burden.

The consumer risk assessment is not finalised due to the identified data gaps on the identity and toxicological profile of metabolites coded 1, 2, and 3 in raw apples, the nature of the breakdown products under processing conditions, the potential occurrence of nitrosamines in raw and processed apples and the storage stability of diphenylamine residues in the residue trials samples.

The only data available in the dossier that were pertinent to the fate and behaviour of diphenylamine in the environment were the results that it exhibits moderate water solubility, is stable to sterile aqueous hydrolysis, exhibits very low persistence in direct aqueous photolysis experiments in the laboratory (optimised light conditions) and is moderately volatile. Indirect photooxidation in the atmosphere through reaction with hydroxyl radicals was also estimated. However it was concluded that despite these limited data, as a consequence of the applied for intended use of diphenylamine, this information was sufficient to characterise the environmental risk at the EU level as exposure of soil, surface water and sediment and consequently groundwater would be expected to be negligible. Though diphenylamine is moderately volatile, significant concentrations in air would not be expected as this property will be counteracted by its moderate water solubility. Diphenylamine would not be expected to have the potential for long range atmospheric transport due to its expected potential for indirect photochemical oxidative degradation in the atmosphere.

The submitted data suggest a low acute and short-term toxicity of diphenylamine to birds and a low acute toxicity to mammals. Exposure of birds and mammals from the representative use as an indoor drench treatment of apples is considered unlikely. Diphenylamine is very toxic to aquatic organisms. However exposure of aquatic organisms is considered to be negligible. Management measures tailored to local practice and legislation should be put in place to control the waste disposal of spent application solution and prevent accidental spillage entering sewers or surface water drains.

No data were made available for other non-target organisms. However exposure of non-target organisms is assumed to be unlikely if the product is applied according to the GAP and studies are considered not necessary. The risk to biological methods of sewage treatment was assessed as low.

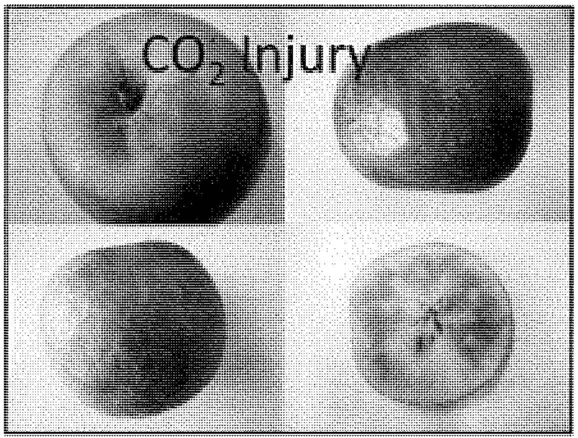
KEY WORDS

diphenylamine, peer review, risk assessment, pesticide, plant growth regulator

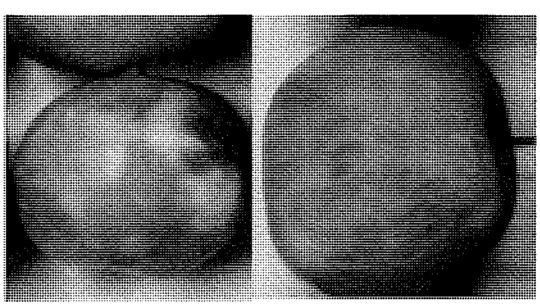
CO_2 Injury/Scald control without DPA

Chris Watkins
Cornell University
Ithaca, NY

CO_2 Injury



Occurs early during storage



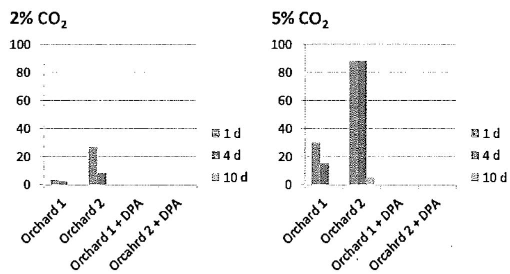
Two control strategies

1. Diphenylamine (DPA)
   - General issues about pesticides on fruit
   - Specific concern about banning in Europe and continued export program

2. Delayed exposure to carbon dioxide in CA storage

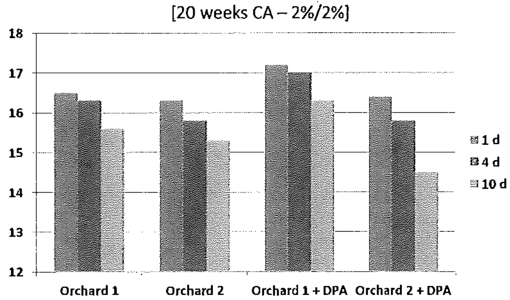
Effects of Delays before CA storage and DPA on CO_2 injury [20 weeks CA]

(Watkins, Silsby and Goffinet, 1997)



Effects of Delays before CA storage and DPA on Firmness (lb-f)

[20 weeks CA – 2%/2%]

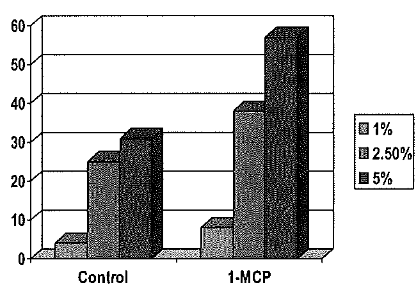


009

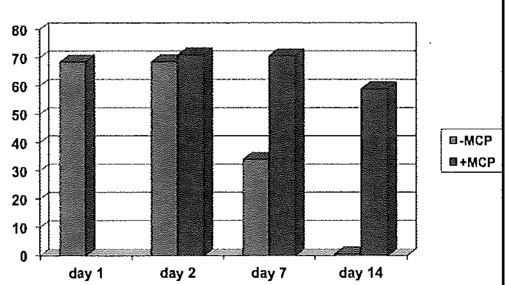
THE NEW WORLD OF SMARTFRESH (1-MCP) AND CARBON DIOXIDE INJURY

SmartFresh can make fruit more susceptible to CO_2 injury

External CO_2 injury in Empire apples stored in 1, 2.5 and 5% CO_2 for 20 weeks

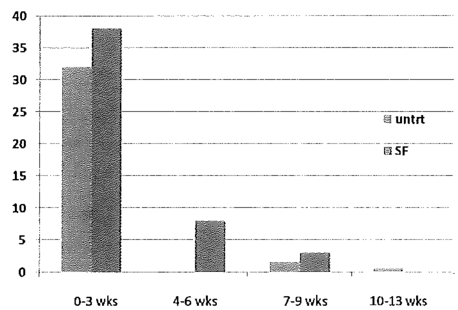


External CO_2 (%) injury in 'Empire' apples untreated or treated with SmartFresh and then with 5% CO_2



Fawbush, Nock, Watkins

Effect of exposing fruit to 5% CO_2 for 3 week periods during storage
(otherwise, 1% CO_2 in 2% O_2)



Managing 'Empire' apples without DPA
Three major strategies

1. Do not use SmartFresh.
2. Apply SmartFresh no sooner than one week after harvest.
3. Apply SmartFresh normally and delay CA about 2 weeks after last treatment.

All strategies assume attention to CO_2 (<1%) during loading and during first 4-6 weeks

Strategy 1

Do not use SmartFresh, fast cooling, with delays of at least 5 days before CA conditions are applied.

- Downside is softer fruit especially through the market chain

Strategy 2

2. Apply SmartFresh no sooner than one week after harvest

   Trying to take advantage of loss of fruit sensitivity to CO_2 after harvest

You get the advantage of SmartFresh while reducing injury risk, but serious management issue

- On day 7, fruit within a room could range from 1-6 days after harvest (high to low risk in same storage room).

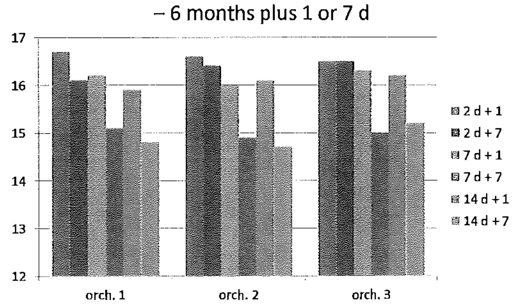
Strategy 3

3. Apply SmartFresh normally and delay CA about 2 weeks after last treatment.

- Application of SmartFresh quickly means a significant degree of flexibility in CA management

Effect of delays (2, 7 or 14 days) between harvest and CA storage – no 1-MCP

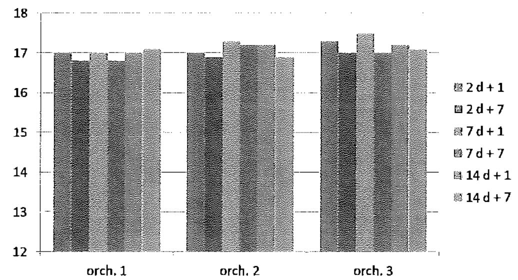
– 6 months plus 1 or 7 d



- Hudson Valley (IEC = 0.4-3.6ppm)

Effect of delays (2, 7 or 14 days) between harvest and CA storage

– fruit treated with 1-MCP after overnight cooling

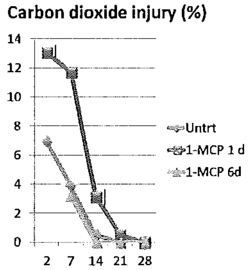


- Hudson Valley (IEC = 0.4-3.6ppm)

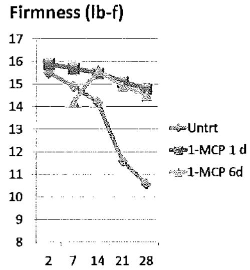
Delayed CA (2012)

With and without SmartFresh

Carbon dioxide injury (%)



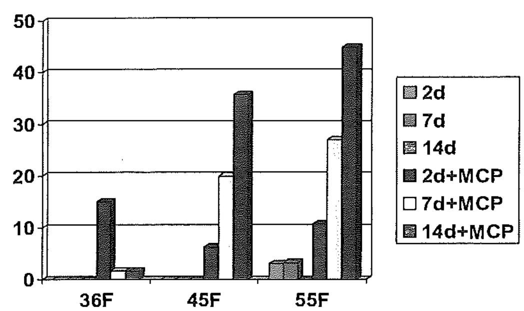
Firmness (lb-f)



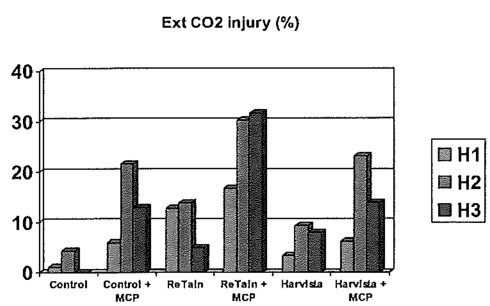
Other factors:

1. Cooling of fruit may be more critical if SF-treated, and if not DPA treated.

- Harvested fruit from McIntosh and Empire blocks, cooled overnight to 36, 45 and 55F, and then treated with SF.
- Kept fruit at these temperatures for 2, 7 and 14 days, cooled to 36F and applied CA.



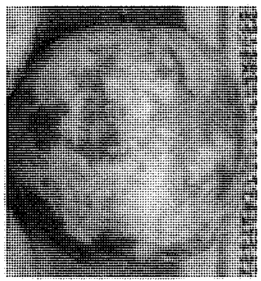
2. Effect of preharvest Plant Growth Regulators

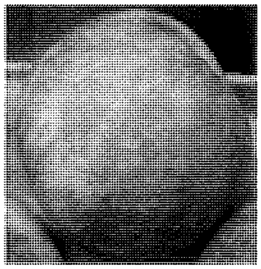


Other factors that may help

- Add lime to room as it is being loaded and monitor room CO_2 levels.
- 1% CO_2 in storage atmosphere for 4-6 weeks, then increase to 2%. (in 2% O_2).
- Develop block histories

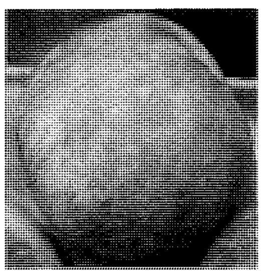
Superficial scald





Scald development – the dogma

- Alpha-farnesene is a key metabolite (substrate) in scald development.
- Free radical production during oxidation of farnesene to produce CTols is thought to result in injury.



Different mechanisms for control of scald by DPA and 1-MCP

- **<u>DPA</u> has little effect on production of ethylene and farnesene, but prevents farnesene oxidation**
- **<u>1-MCP</u> inhibits production of ethylene and subsequently farnesene, i.e. prevents substrate formation**

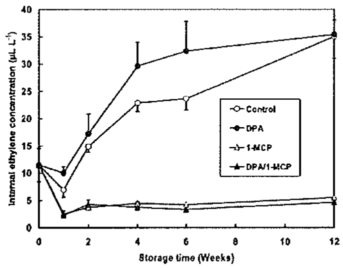


Figure 3. Internal ethylene concentrations in Delicious apple fruit untreated or treated with 2 g L^{-1} DPA and then treated with either air or 1 $\mu L\ L^{-1}$ 1-MCP for 24 h, and kept at 0.5 °C for 12 weeks. Each data point represents the mean of four replicates of 10 individual fruit + 1 SE. All differences between non-1-MCP treatments and 1-MCP treatments are significant ($P < 0.001$).

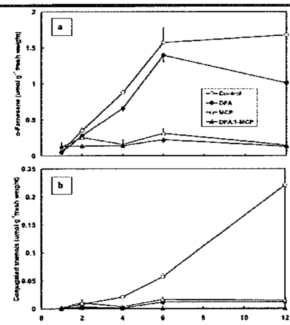
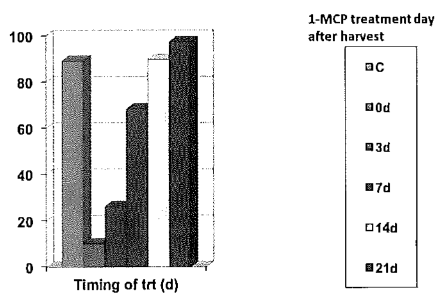
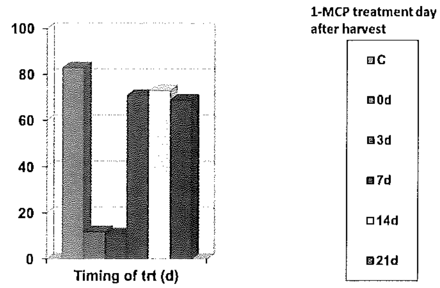


Figure 4. α-Farnesene (a) and conjugated trienol (b) concentrations in peel tissue of Delicious apple fruit untreated or treated with 2 g L^{-1} DPA and then treated with either air or 1 $\mu L\ L^{-1}$ 1-MCP for 24 h, and kept at 0.5 °C for 12 weeks. Each data point represents the mean of four replicates of bulked samples of 10 peeled fruit + 1 SE. For α-farnesene, the differences between the non-1-MCP treatments and 1-MCP treatments are significant ($P < 0.001$), and for conjugated trienols, differences between the untreated control and other treatments are significant ($P < 0.001$).

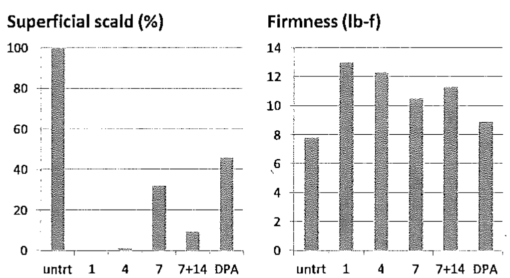
Timing of SmartFresh treatment on superficial scald (%) – Cortland (24 weeks air)



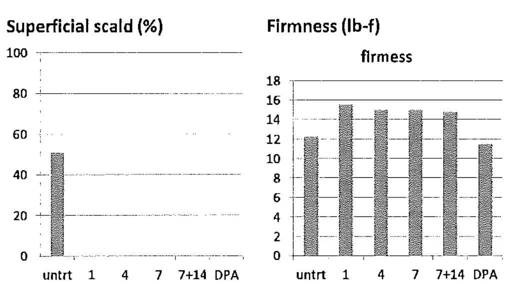
Timing of SmartFresh treatment on superficial scald (%) – Law Rome (24 weeks air)



Timing of SmartFresh in Cortland on scald and firmness (36 weeks CA)



Timing of SmartFresh in Delicious on scald and firmness (36 weeks CA)



Superficial scald and SmartFresh

- 1-MCP provides excellent alternative to DPA, but control of ethylene production is critical
  - **Where postharvest treatment of fruit with 1-MCP is not applied appropriately, or effects wear off, then efficacy decreases dramatically**
  - **Apples like Delicious – great flexibility**
  - **McIntosh and Cortland – little flexibility. Storage time and factors that delay loss of SF inhibition of ripening critical [growing region, harvest date, air vs. CA]**

May have conflict with carbon dioxide injury!

Storage Disorders when Not using DPA

Dr. Jennifer DeEll
Fresh Market Quality Program Lead
OMAFRA, Simcoe, Ontario

Ontario

2013 Trials

Experiment 1

Question – How long does it take for McIntosh exposed to CO_2 to develop CO_2 injury?

Experiment 2

Question – Does cooling rate affect the incidence of CO_2 injury in McIntosh and Empire?

DeEll, 2014

'McIntosh' - 2013

Experiment 1

+ SmartFresh, day of harvest

~17% O_2 + ~4% CO_2 at 3°C

Harvest = Sept. 9

Pioneer
13.5 lb, 0 ppm,
4.5 starch

Summerland
15.8 lb, 0.1 ppm,
4.5 starch

* Harvest 1 next expt.

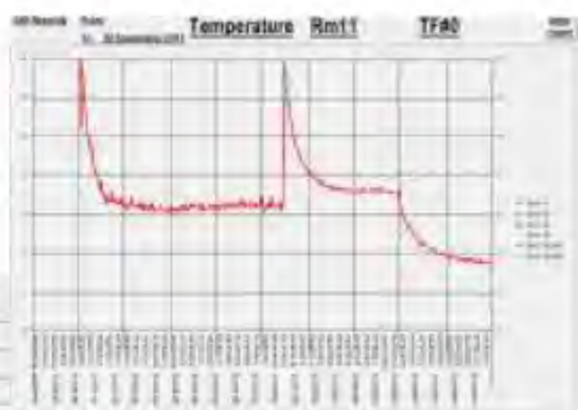
	External CO_2 Injury (%)	
	Pioneer	Summerland
1 week	0	0
2 weeks	0	0
4 weeks	0	0.8
6 weeks	0.7	6.1
	****	

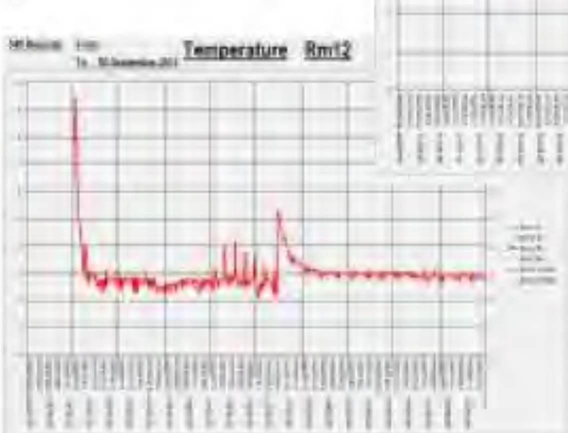
DeEll, 2014

'McIntosh' - 2013

Experiment 2a

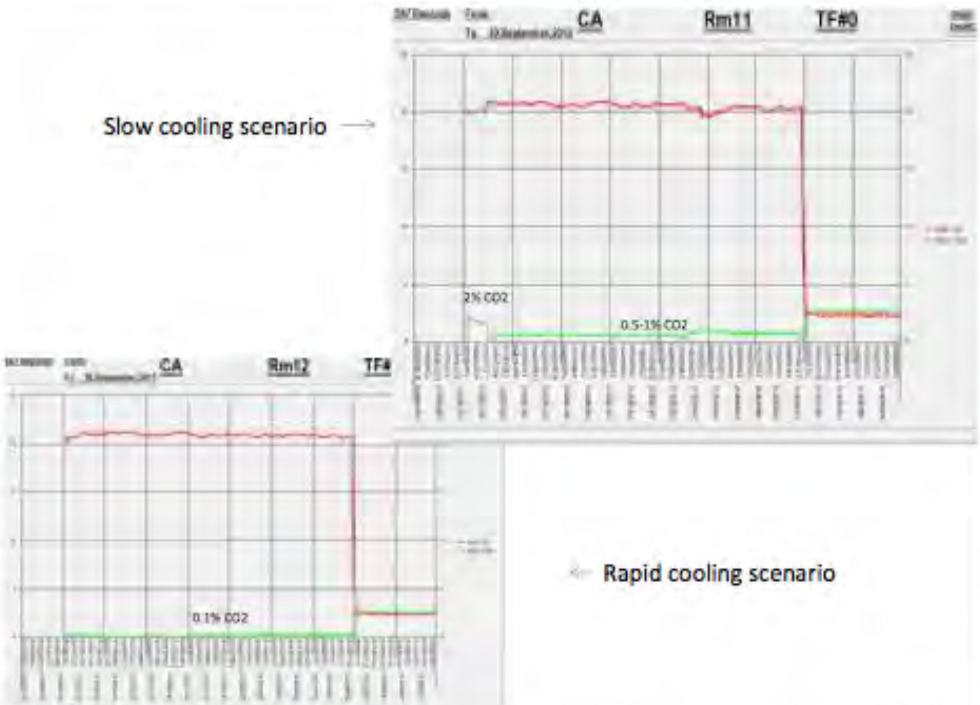
Slow cooling scenario →





← Rapid cooling scenario

DeEll, 2014



Slow cooling scenario

Rapid cooling scenario

DeEll, 2014

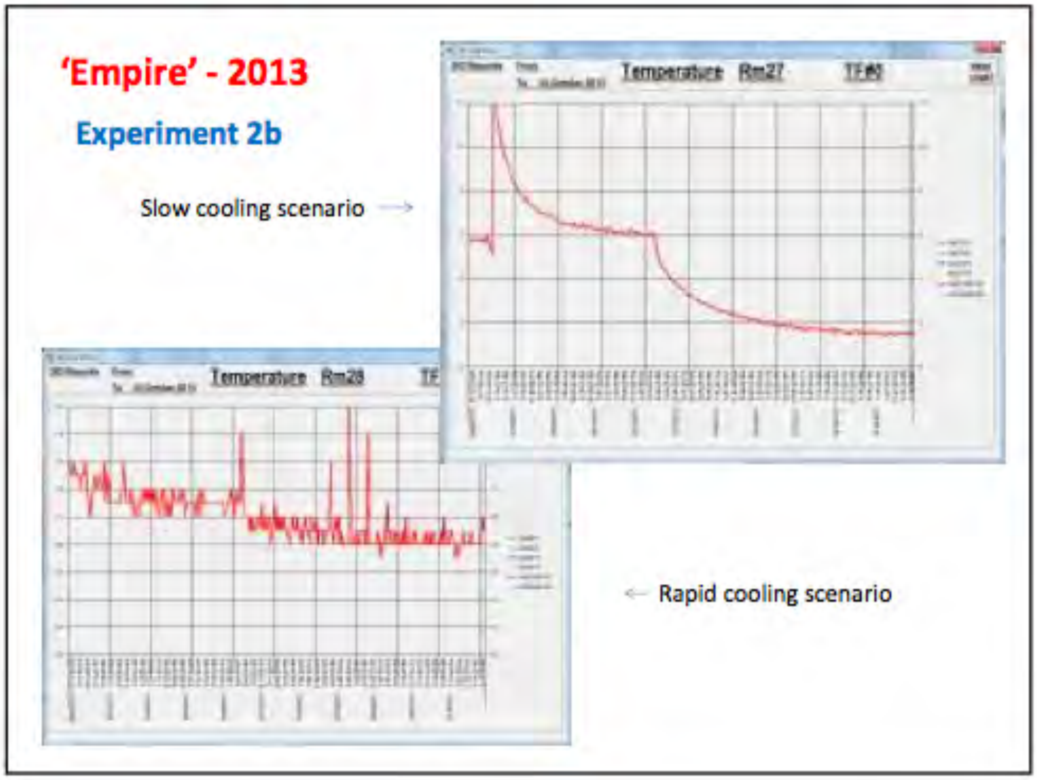
'McIntosh'

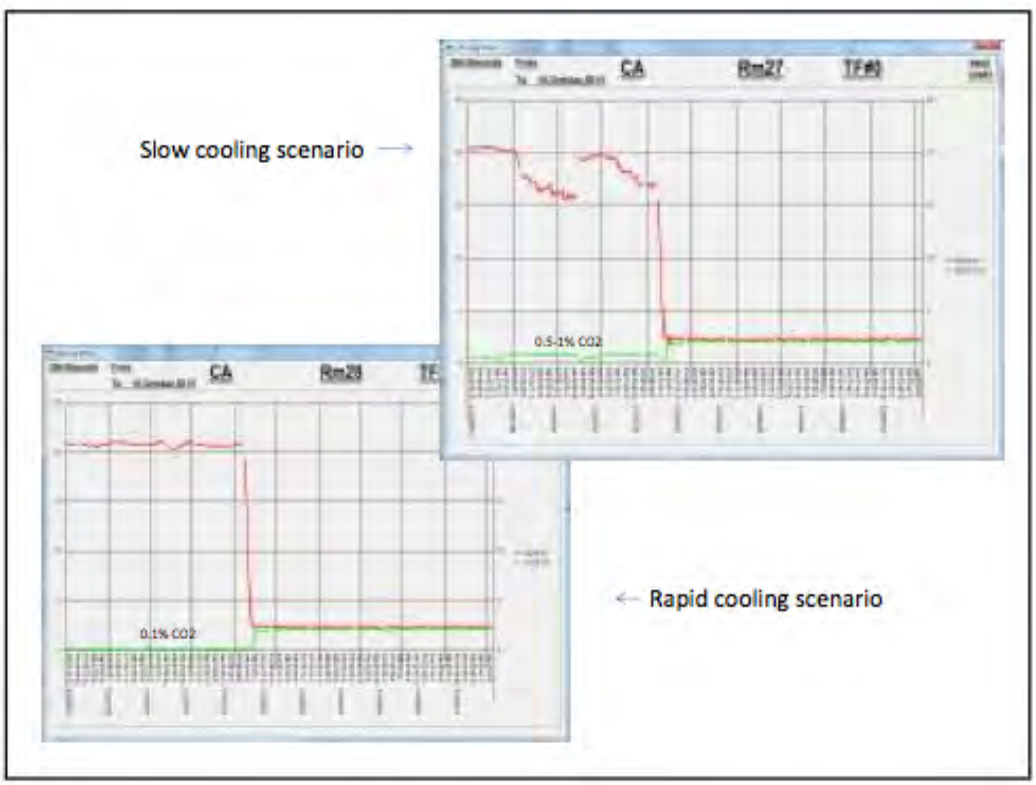
SCA (2.5% O_2 + 2.5-4.5% CO_2) at 3°C, 8 months

	Weight Loss (%)		External CO_2 Injury (%)		Flesh Browning (%)	
	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2
No SmFr						
Rapid	1.1^{d}	0.8^{f}	6^{c}	0^{d}	17	8
Slow	1.4^{b}	1.3^{c}	1^{d}	0^{d}	11	8
+ SmFr						
Rapid	1.0^{e}	0.6^{g}	18^{b}	16^{b}	11	8
Slow	1.5^{a}	1.1^{d}	52^{a}	57^{a}	11	10
	****		****		NS	

* Prior to cooling, all held at 62°F overnight (+/- SmartFresh)

DeEll, 2014


'Empire' - 2013
Experiment 2b
Slow cooling scenario
Temperature Rm27 TF#0
Temperature Rm28
Rapid cooling scenario


Slow cooling scenario
CA Rm27 TF#0
0.5-1% CO2
CA Rm28
0.1% CO2
Rapid cooling scenario

'Empire'

* Prior to cooling, all held at 62°F overnight (+/- SmartFresh)

SCA (2.5% O_2 + 2% CO_2) at 1-2°C, 8 months

	Weight Loss (%)	External CO_2 Injury (%)	Internal CO_2 Injury (%)	Flesh Browning (%)	Core Browning (%)
No SmFr					
Rapid	1.2 c	26 c	4	22	11
Slow	1.8 a	41 bc	16	15	7
+ SmFr					
Rapid	1.1 c	60 ab	6	33	10
Slow	1.5 b	74 a	15	14	1
	****	**	NS	NS	NS
Rapid vs. Slow Main effect	****	****	****	NS	NS

DeEll, 2014

Effect of Delayed CA on the Quality of 'Empire' Apples in Long-Term Storage

(DeEll et al., published in PBT 2012)

- 'Empire' apples
- Cooled overnight after harvest
- SmartFresh treatment to maintain firmness
- 24 hour SmartFresh, 1 ppm 1-MCP
- 0, 1 or 2 months of air storage at 1°C
- Followed by SCA (2.5% O_2 + 2% CO_2) at 3°C
- Total of 9 months storage

DeEll, 2014

	Flesh Browning (%)	External CO_2 Injury (%)	Firmness (lb) Day 1	Firmness (lb) Day 7 at RT
Year 1			(16.9 lb at harvest)	
No delay	64^{a}	30^{a}	13.4^{a}	11.4^{b}
2 mo delay	26^{b}	$<1^{b}$	13.4^{a}	11.6^{b}
Year 2			(15.6 lb at harvest)	
No delay	12^{a}	25^{a}	13.2^{a}	12.5^{ab}
1 mo delay	7^{ab}	0^{b}	12.9^{ab}	11.7^{cd}
2 mo delay	3^{b}	0^{b}	12.3^{bc}	11.3^{d}

* No significant effect on core browning

RT = room temperature, ~20°C

DeEll, 2014

Storage Strategies (with SmartFresh)

For cultivars susceptible to CO_2 injury

e.g. 'McIntosh', 'Empire', 'Cortland'

- SmartFresh + DPA = Ok
- If SmartFresh but no DPA…
  - Beware of CO_2 increases during room loading
  - Cool fruit before SmartFresh and CA
  - Do not rush CA establishment
  - Keep CO_2 <0.5% for first 30-60 days
  - Gradually increase to standard concentration
  - Note - ReTain increases susceptibility to CO_2 injury

DeEll, 2014

Acknowledgements / Collaborators

Ontario Apple Growers

Norfolk Fruit Growers' Association

Apple Marketers' Association of Ontario

CHC – Apple Working Group

AgroFresh Inc.

Storage Control Systems Inc.

Pommes Philip Cassidy Inc.

Agriculture and Agri-Food Canada

Research Assistants –

Behrouz Ehsani-Moghaddam

Lorie Walker

DeEll, 2014

Delayed CA Storage Reduces Disorders in ‘Empire’ Apples

Dr. Jennifer DeEll, Fresh Market Quality Program Lead, OMAFRA, Simcoe

The objective of this study was to investigate the effect of delayed controlled atmosphere (CA) on the development of storage disorders in ‘Empire’ apples, in combination with postharvest 1-methylcyclopropene (1-MCP, SmartFresh) treatment to maintain fruit firmness during long-term storage. ‘Empire’ apples were harvested near the beginning of the commercial harvest period in both 2009 and 2010. Internal ethylene concentration was relatively low (<2 ppm), the starch index was less than 5, and fruit firmness ~16.3 lb. Fruit were cooled overnight and then treated with or without SmartFresh (1 ppm 1-MCP, an ethylene inhibitor) for 24 hours at 3°C. Apples were subsequently held either in CA storage (2.5% O_2 + 2% CO_2) at 3°C for 9 months or in ambient air at 1°C for 1 or 2 months and then CA storage at 3°C for 8 or 7 months (delayed CA), respectively.

SmartFresh-treated apples with a 2-month delay in CA establishment had less external CO_2 injury and flesh browning during both years of study (Table 1). Delayed CA for 1 month could also reduce the incidence of these disorders. However, there was not always a significant effect of delayed CA on core browning. These results suggest that there are different mechanisms associated with the development of these storage disorders, especially in relation to ethylene. It is important to note that no apples in this study were treated with diphenylamine (DPA), which can control CO_2 injury.

SmartFresh improved firmness retention of ‘Empire’ during long-term CA storage, even when CA establishment was delayed (Table 1). For example, apples treated with SmartFresh had similar firmness with a 2-month CA delay as those with no delay, after 9 months of storage and 7 days of shelf-life at 24°C in the first year of study. There was little effect of delayed CA on internal ethylene, soluble solids, or titratable acidity (data not presented).

Overall, the results suggest that delaying CA storage to reduce the development of certain storage disorders in ‘Empire’ apples could be utilized in combination with SmartFresh treatment to retard fruit softening during long-term storage. This may be an acceptable compromise for reducing fruit losses due to storage disorders while maintaining acceptable firmness for the marketplace. However, further research is needed to determine the effects of fruit maturity at harvest time and shorter delays in CA establishment, as well as to assess fruit quality after various CA storage durations.

Table 1: Storage disorders and firmness of 'Empire' apples held either in CA storage (2.5% O_2 + 2% CO_2) at 3^oC for 9 months (No Delay) or in ambient air at 1^oC for 1 or 2 months and then CA storage at 3^oC for 8 or 7 months (1 or 2 mo. CA Delay, respectively), plus 7 days at 24^oC.

	External CO_2 injury (%)	Flesh browning (%)	Core browning (%)	Firmness (lb)
<u>2009</u>				
No SmartFresh				
No CA Delay	5	69	92	9.6
2 mo. CA Delay	4	40	53	7.5
+ SmartFresh				
No CA Delay	30	64	74	11.4
2 mo. CA Delay	0	26	58	11.6
<u>2010</u>				
No SmartFresh				
No CA Delay	25	31	38	8.8
1 mo. CA Delay	0	10	32	7.3
2 mo. CA Delay	1	9	27	7.4
+ SmartFresh				
No CA Delay	25	12	4	12.5
1 mo. CA Delay	0	7	5	11.7
2 mo. CA Delay	0	3	7	11.3

An Automated In-Orchard Apple Sorting System for Achieving Cost Savings for Growers (and Packers)

Renfu Lu

USDA Agricultural Research Service
Biosystems & Agric. Engineering Dept.
Michigan State University

Presentation Outline

- Justification for infield sorting
- Goal and objectives
- Major features of infield sorting prototype
- Field demonstration in 2013
- Summary and future plan

Major Issues for Fruit Growers

- Labor availability and cost
  - Harvest and postharvest packing are major cost components in apple production
- Product quality, consistency and traceability
- The environmental sustainability

Current Commercial Apple Harvesting Technologies

Picker Technologies & Oxbo, US

DBR Harvester, Michigan, US

Munckhof, Europe

Major features:
- Self propelled or dedicated system
- Vacuum or mechanical delivery
- No or limited sorting capabilities
- High cost in machinery

Current Commercial Packinghouse Sorting Technologies

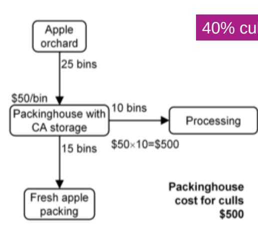
Major features:
- Highly efficient, large scale
- Precision sorting for color, size, weight, and/or defect
- Sort as many grades as needed
- Very high in machinery cost

Justification for Infield Sorting

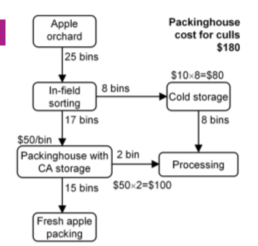
Costs for postharvest storage, sorting and grading ($/bin)

CA Storage	Cold Storage	Sorting/Grading for Fresh Apples	Sorting/Grading for culls
$20	$10	$40	$30

40% cull rate



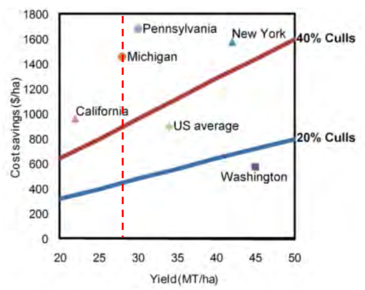
Current postharvest handling flow



Postharvest handling flow with in-field sorting

Potential Cost Savings for Apple Growers by Adoption of Infield Sorting

(20% and 40% cullage rates)



(Mizushima, A. & R. Lu. 2011. Appl. Eng. Agric. 27: 33)

Benefits of Infield Sorting

- Reduce postharvest storage/packing cost by separating culls in the orchard
- Reduce postharvest pest/disease problems
- Improve inventory management & packout rate
- Enhance product traceability

Current harvesting practice

Goal and Objectives

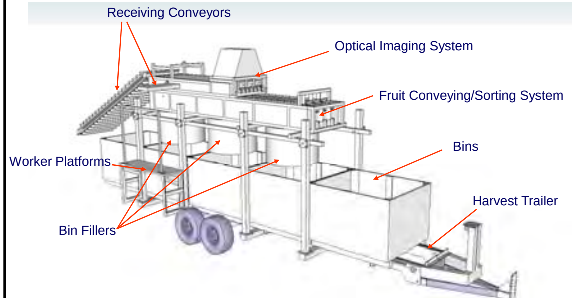
Develop commercially viable technology to presort and grade apples in the orchard so as to decrease postharvest handling and storage costs for fruit growers. The project included the following tasks:

- Low-cost machine vision-based inspection system for sorting/grading apples for size, color, and defect;
- Effective fruit delivery/handling systems or modules suitable for in-orchard sorting/grading;
- Integration of harvest aid functions to enhance harvest efficiency and worker safety.

Design Requirements for In-orchard Harvesting and Sorting System

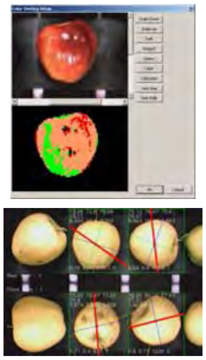
- Low in cost (~ $30K-$50K/unit)
- Mobile, compact, and easy and reliable to operate
- Minimum additional worker time to operate
- Sort into 2-3 grades for size, color and defects
- Sorting speed: ~ 6-8 fruit/s (for 6-8 workers)
- Have harvest aid functions

Schematic of Infield Sorting Prototype

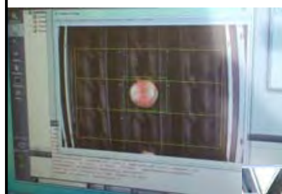


In-Field Sorting Prototype

Machine Vision-Based Grader



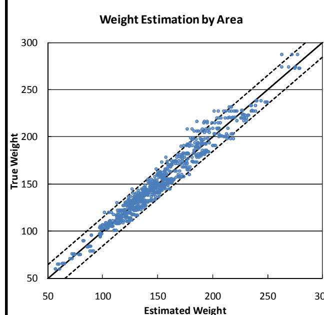
Machine Vision-Based Grader



Color Grading Results
(Compared with a commercial sorter)

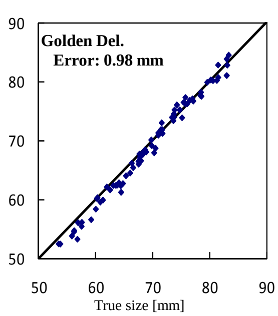
	Cull (180)	Fancy (180)	Extra Fancy (180)
Cull	168	12	0
Fancy	17	153	10
Extra Fancy	0	9	171
Success rate [%]	91%	88%	94%
Global success rate [%]		**91%**	

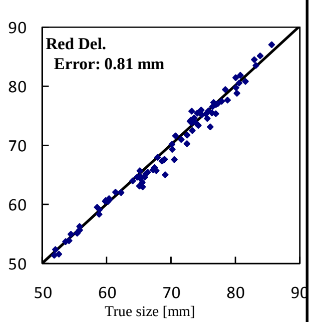
Weight Estimation Results



Variety	Estimation Error (Gram)	(%)
RD	7.7	4.8
GD	4.8	3.1
EM	6.2	4.0

Size Estimation Results



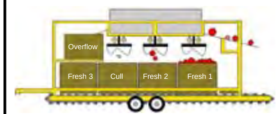


Multiple Bin Fillers

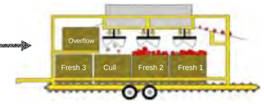
Multiple Bin Fillers

Logistics of Bins Handling

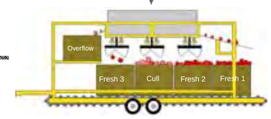
Two-Grade Sorting: Cull and Fresh



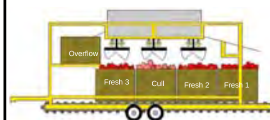
The first fresh bin fills; the second fresh bin is then used.



The second fresh bin fills; the chain moves forward allowing the third fresh bin to be utilized.



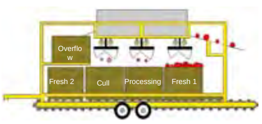
The cull bin becomes full while the third fresh bin is still loading. The remaining cull apples are redirected to the overflow bin until the third fresh bin is full.



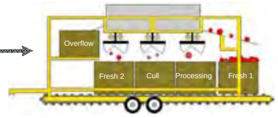
All of the bins (with the exception of the overflow) are completely full and ready for unloading from the trailer.

Logistics of Bins Handling

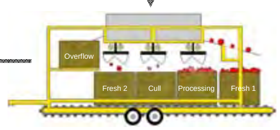
Three-Grade Sorting: Cull, Processing and Fresh



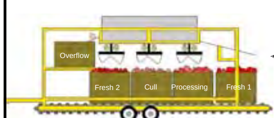
Fill the 1^{st} bin for fresh apples and fill the 2^{nd} and 3^{rd} bins for processing and cull.



The chain is activated to allow the second fresh bin to be accessed.



The processing bin fills; further processing apples are directed to the cull bin.

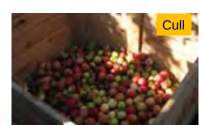


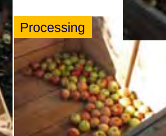
The second fresh and cull bins both fill. In the event that the cull fills first, the remaining cull apples are directed to the overflow bin.

In-Orchard Demonstration (Sept. 2013)

In-Orchard Demonstration (Sept. 2013)

In-Orchard Demonstration (Sept. 2013)





Summary

- An automated in-orchard apple sorting prototype was developed to sort apples into two or three grades.
- The prototype possesses some unique design features for singulation, imaging, and handling of fruit and for delivering fruit to the bins.
- The prototype has limited harvest-aid functions and can accommodate a harvest crew of 6-8 people.
- The infield sorting technology can be easily adapted to different harvest trailers or similar equipment that are already used by growers.

Future Plan

- Develop 2^{nd} version infield sorting system
  - A new fruit sorter that is more compact, reliable and lower in cost than the current version
  - Improved bin filler design for effective and efficient delivery of fruit into bins
  - Enhance harvest aid functions by adding hydraulic platforms and other features
- Develop new algorithms for defects sorting and enhance the traceability of harvested fruit by adding a GPS tracking function and providing detailed information about fruit quality in each bin.
- Field tests and demonstration
- Work with a commercial partner to make the technology available to growers.

Cost Benefits Analysis of In-field Presorting for the Apple Industry

A. Mizushima, R. Lu

Abstract. *In-field apple presorting is intended to separate culls that are only suitable for processing or making into juice from apples that would meet the fresh market requirements, so that growers can achieve cost savings in postharvest storage, grading, and sorting. This article reports on the cost benefits analysis of in-field presorting for the U. S. apple industry. Packinghouse costs for culls that would be saved from in-field presorting and in-field presorting yearly costs were defined and estimated to evaluate potential cost benefits for fresh apple growers, processing apple growers, and packinghouses. For fresh apple growers producing 1,400 bins (508 metric tons) or more, in-field presorting is beneficial if the machinery cost is equal to or less than $30,000 (assuming 7-year machine life, 0.3 full-time labor, and 44 bins/day sorting capacity). Smaller fresh apple growers producing 900 bins (327 metric tons) may also benefit from in-field presorting if the cullage rate is more than 40%. In-field presorting is more beneficial to processing apple growers even when the production capacity is as low as 700 bins (254 metric tons). Presorted apples are more consistent in quality, thus enabling packinghouses to better manage postharvest storage/packing operations to meet the market needs. In addition, a properly designed in-field presorting system can provide information about the origin and quality/condition of fruit in each bin, thus enhancing product traceability. The economic analysis results presented in this article are useful in guiding the development of in-field presorting systems that will ultimately benefit the apple industry.*

Keywords. *In-field presorting, Grading, Apple, Economic analysis, Postharvest, Quality.*

In recent years, apple growers in the United States have been facing significant challenges due to increased competition (domestic and international) and higher production costs (Du Brille and Barritt, 2005). The overall apple production cost in the United States has been on a steady increase because of increased costs in labor, chemicals, and machinery. For example, the U.S. federal minimum wage has increased from $5.85 per hour in 2007 to $7.25 per hour in 2009 (USDOL, 2009). Hence U.S. apple growers are seeking innovative means to enhance yield, quality, and production efficiency (Seavert, 2005). In response to the critical needs of the specialty crop industries, the U.S. Congress authorized the Specialty Crop Research Initiative in the 2008 Farm Bill to develop and disseminate science-based tools and innovative technologies to improve specialty crop production efficiency, competitiveness and profitability.

Apple harvest is still performed by humans, and it is one of the major cost components in apple production. Hence considerable effort has been directed toward development of mechanical harvesters or robotic harvest machines to reduce dependence on labor (Baeten et al., 2008; Bulanon et al., 2004, 2005; Setiawan et al., 2004). However, there are many technical challenges in the development of robotic harvesters and cost is still a major constraining factor for robotic harvest of apples. As an alternative solution, harvest assisting technologies have been or are being developed to enhance harvest efficiency (Warner, 2009a). These technologies have not been widely adopted in the United States because they still require significant capital investment from growers and because they cause excessive bruising during fruit handling (Faubion, 2005; Robinson, 2008). In the past few years, mobile orchard platforms have received considerable attention; they can achieve productivity improvement for operations like thinning and harvesting of peaches and apples, if the orchards are well structured or have uniform canopy and the row spacing is suitable for the platforms (Baugher et al., 2006, 2009). Precision farming provides another means to enhance profitability (Giles and Downey, 2003; Qiao et al., 2005). With knowledge of fruit yield and quality in the orchard, growers can make better production and harvest decisions so as to enhance product quality and thus profitability. Moreover, as consumers are demanding safer fresh fruit, product traceability is becoming an increasingly important issue for the apple industry (Bollen et al., 2007; Riden and Bollen, 2007; Moe, 1998), which requires knowledge of product origin and history from production to postharvest storage/handling to retailing.

Postharvest storage and handling in the packinghouse is another major cost component in apple production (Wunderlich et al., 2007). With current harvest practices, all harvested fruit of different quality grades are placed into the same fruit bins and then trucked to the warehouse. After storage, the apples are graded and sorted. Growers pay almost the same cost for storage, grading, and sorting of culls as that

---

Submitted for review in March 2010 as manuscript number PM 8467; approved for publication by the Power & Machinery Division of ASABE in November 2010.

The authors are **Akira Mizushima, ASABE Member,** Agricultural Engineer, and **Renfu Lu, ASABE Member Eng**ineer, Supervisory Agricultural Engineer; United States Department of Agriculture, Agricultural Research Service, Michigan State University, East Lansing, Michigan. **Corresponding author:** Akira Mizushima, United States Department of Agriculture, Agricultural Research Service, 207 Farrall Hall, Michigan State University, East Lansing, MI 48824; phone: 517-353-7793; fax: 517-432-2892; e-mail: Akira.Mizushima@ars.usda.gov.

for marketable apples. Because of high costs for packinghouse operations (i.e., storage, grading, and sorting), growers may not break even if the apples are of low quality grade and have a high percentage of culls. For this reason, some growers have begun doing in-field presorting manually to reduce the amount of culls delivered to the packinghouse (Schtzko and Granatstein, 2005). While this practice incurs additional costs at harvest, it reduces packinghouse charges, which may more than offset the cost increase in the orchard. Because of the high cost of sending culls to the packinghouse, growers must keep damage to fruit at minimum. Hence intensive pest/disease management is needed. With adoption of in-field presorting practices, growers may tolerate more fruit damage and thus reduce the use of pesticides and biocontrol measures in the orchard because inferior or defective apples are removed (Warner, 2009b). Moreover, with removal of inferior or defective apples, pest/disease problems can be greatly reduced during postharvest storage (Hansen, 2009). In addition, a properly designed presorting system can provide information about the quality (size, color, maturity) and origin of fruit in individual fruit bins to enhance inventory management. Furthermore, packinghouses can achieve higher packout rate for the presorted apples, thus improving the packing efficiency.

Because of these potential benefits, presorting technology has been identified as one of the top technologies that would have great impact on the apple industry for the next decade (Hanson, 2009).

Currently, no appropriate presorting technology is available, and there are doubts and questions about the cost effectiveness of adopting this practice. The overall objective of this research is, therefore, to develop a cost effective in-field apple presorting system to remove culls that are only suitable for processed products (juice, applesauce, canning, dried, etc.), so that growers can achieve production cost savings. To guide the development of presorting technology, it is important to perform cost benefits analysis of in-field presorting practices. This article first provides a brief overview of the U.S. apple industry. It then presents packinghouse costs for culls that would be saved by adoption of an in-field presorting system and estimated yearly in-field presorting costs. Next, cost benefits for fresh apple growers, processing apple growers and packinghouses are analyzed and discussed. And finally, guidelines on the development of a cost effective in-field presorting system are provided.

Overview of the U.S. Apple Industry

There were an estimated 7,300 apple growers (>2 ha or 5 acres) in the United States with a total of 152,842 ha (377,680 acres) in 2007, trailing only oranges and grapes in acreage committed to fruit production (USDA, 2009a). The average orchard size was 21 ha (52 acres) and the average yield was 30 metric tons/ha (table 1). In 2007, the total apple production in the United States was 4,122.9 kilo metric tons, 67% of which were sold as fresh fruit and the remaining being processed into apple products including juice. Almost 90% of the U.S. apples were produced by the five states listed in table 1. The state of Washington produced about 57% of the apples in the United States, followed by New York and Michigan, each producing approximately 15% and 9%, respectively. The percentage of apples for processing varied greatly by state, ranging from 16% for Washington to 70% for Pennsylvania. The state of Washington was the only state that produces less than 20% culls. The other four states had more than 40% cullage rate, even though the national average cullage rate was only 33% because of the disproportionally large production share and an exceptionally low cullage rate by the state of Washington. If Washington state were excluded, the U.S. average cullage rate would be 55%. These statistics do not accurately reflect the actual apple grower's situation in the United States, because many growers in those states other than Washington produce apples specifically for processing. Generally, the farms for fresh market apple production are much more intensively managed compared to those for processing, and they tend to have lower cullage rates. Accordingly, the cullage rate for "fresh apple" growers in those states would be lower than the actual statistic data shown in table 1.

Methods and Procedures

Packinghouse Costs for Culls Saved by In-field Presorting

Many packinghouses in the United States have instituted an in-charge per bin [363-454 kg (800-1000 lb)] to encourage growers to deliver only fresh-pack quality fruit (Schtzko and Granatstein, 2005). Regular (i.e., refrigerated air) storage, grading, and sorting costs are usually included in the in-charge. There are additional, separate charges for controlled atmosphere (CA) storage and for packaging and sales. Thus growers must pay the charge even if none of the fruit goes to the higher-value fresh market. In this article, the total cost of storage, sorting, and grading is referred to as the packinghouse cost. Based on the information obtained from three major packinghouses in Michigan in 2009, the sorting and grading costs for fresh apples were between \$33/bin and \$45/bin. For culls, the costs varied from \$29/bins to \$33/bins. The packinghouse charges in the state of New York are similar to those in Michigan (Mike Rothwell of BelleHarvest, Mich., personal communication). Schtzko and Granatstein, (2005) reported that the minimum charges for the 2001 crop

Table 1. Summary of the statistical data for U.S. apple production for 2007 (USDA, 2009a and 2009c)

State	Production Area (ha)	Farms	Average Farm Size (ha)	Average Yield (MT/ha or bins/acre)	Total Production (× 1000, MT)	Processed Apples MT, ×1000	Processed Apples % Cullage Rate
Washington	54,457	1,839	30	40 (45 bins)	2,358.7	385.6	16
New York	19,253	701	28	38 (42 bins)	594.2	276.7	47
Michigan	17,338	894	19	25 (28 bins)	349.3	229.1	65
Pennsylvania	8,494	498	17	27 (30 bins)	213.2	149.7	70
California	8,098	502	16	20 (22 bins)	156.5	86.2	55
US, Total	152,842	7,262	21	30 (34 bins)	4,122.9	1,346.3	33

in Washington were estimated to be $7.00 per 42 lb (19.05 kg) for 'Red Delicious', $7.20 for 'Granny Smith', 'Fuji', and 'Jonagold', and $7.50 for 'Golden Delicious', 'Gala', and 'Rome'. Based on these estimates, the charges for storage, grading, and sorting were estimated to be $3 per 42-lb (19.05 kg) carton, or $54 per bin (there are about 18 cartons per bin). Wunderlich et al. (2007) reported an estimated cost of $8 per 40 lb (18.14 kg) carton for sorting, grading, packaging and selling in California. Hence an estimated charge of $3 per carton or $54 per bin for storage, grading and sorting seems reasonable.

Based on the packinghouse charge estimates for Michigan and other states, we chose $60 per bin for fresh apples (CA storage plus sorting and grading for fresh apples) and $50 for cullage apples (CA storage plus sorting and grading for culls) in our analysis. The estimated packinghouse costs are listed in table 2, and they are fair or below average for the U.S. apple industry. Hence the cost benefits analysis reported in the article would provide more conservative estimates.

In the current postharvest handling flow (fig. 1), apple growers bring all harvested apples to the packinghouse regardless of apple quality in each bin. Assume that a grower brings to the packinghouse 25 bins of apples with the cullage rate of 40% or 10 bins. If the packinghouse cost for each cullage bin is assumed to be $50 based on table 1 (i.e., $30/bin for sorting and grading plus $20/bin for CA storage), the total packinghouse cost for the 10 bins of culls is $500. On the other hand, if in-field presorting is adopted, the packinghouse cost for cullage apples will be reduced to $180, as shown in figure 2. The packinghouse cost for the culls is $100 and the cold storage cost is $80. The difference between the conventional packinghouse cost for culls and the cost for culls with in-field presorting is $320 in this example of 25 bins with 40% cullage rate. In this cost estimation, weassumed 80% of the cullage apples would be sorted out by the in-field presorting system, which means that 20% (two bins) of the cullage apples go to the packinghouse and the remaining 80% (eight bins) directly go to cold storage for processing. This assumption was primarily based on such a consideration that a presorting system can achieve close to 100% removal rate for undersized or off-color fruit, but it would only have limited defect sorting capabilities compared to packinghouse sorting systems. The actual cull sort-out rate for a presorting system will vary, depending on the relative percentages of undersized or off-color fruit and defective fruit, which, in turn, depend on such factors as production region, orchard, variety, season, etc.

Table 2. Packinghouse storage, sorting, and grading costs.

Packinghouse Services	Cost/bin
CA storage[a]	$20/bin
Cold storage[b]	$10/bin
Sorting and grading for fresh apples	$40/bin
Sorting and grading for culls	$30/bin

[a] CA storage stands for "Controlled Atmosphere" storage used for longer storage.
[b] Cold storage is regular, refrigerated storage used for short-term storage.

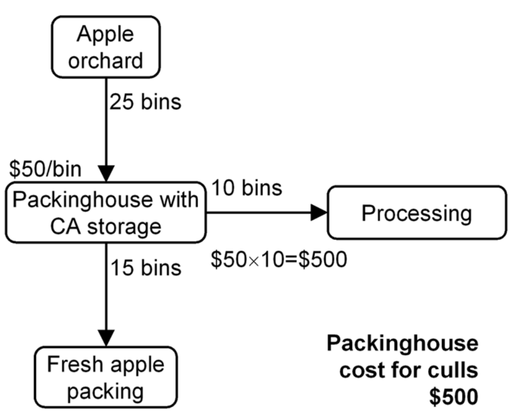


Figure 1. Conventional postharvest handling flow (assuming 40% cullage rate).

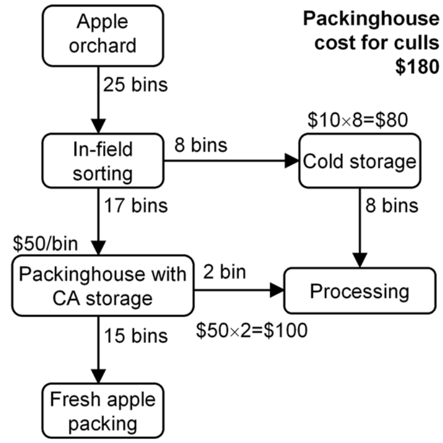


Figure 2. Postharvest handling flow with in-field presorting (assuming 40% cullage rate and 80% cull sort-out rate).

Packinghouse costs per hectare for culls saved by in-field presorting with various yields (MT/ha) and cullage rates are shown in table 3. The range of yields is between 20 and 50 MT/ha and the cullage rate ranges from 20% to 40%. Even though many states listed in table 1 have more than 40% cullage rate in production, cost savings in the packinghouse for more than 40% cullage rate are not calculated because such a high cullage rate may not be realistic for "fresh apple" growers. And there is also a high possibility that exceptionally high cullage rates will be rejected by packinghouses. Packinghouse cost savings for culls per hectare by adoption of in-field presorting range from $320 to $1600 (table 3). Figure 3 shows cost savings per hectare for culls in the packinghouse with in-field presorting for various combinations of yields and cullage rates. The states listed in table 1 are plotted in figure 3. The average grower potentially can save $898/ha ($363/acre) by adoption of in-field presorting practices. The state with the highest cost savings is Pennsylvania [$1680/ha ($680/acre)] and the lowest

Table 3. Packinghouse cost savings per hectare for culls by in-field presorting for various yields and cullage rates.

MT/ha	20% Culls ($)	30% Culls ($)	40% Culls ($)
20	320	480	640
25	400	600	800
30	480	720	960
35	560	840	1,120
40	640	960	1,280
45	720	1,080	1,440
50	800	1,200	1,600

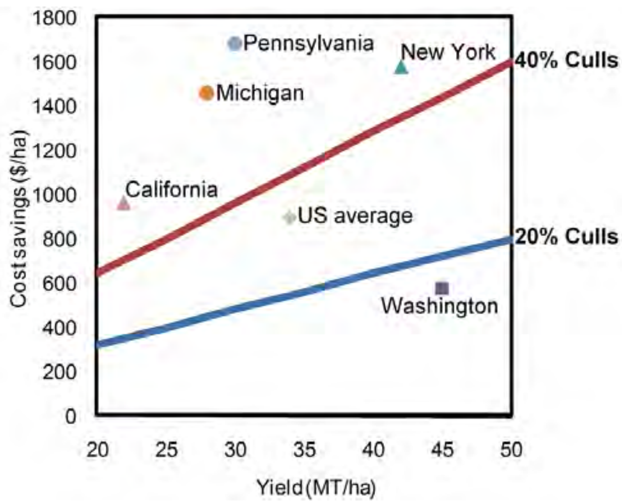


Figure 3. Packinghouse cost savings for culls per hectare by adoption of in-field presorting for different production yields and cullage rates for the five major apple producing states and the U.S. average.

savings state is Washington [$576/ha ($233/acre)]. New York is the second followed by Michigan. New York has a lower cullage rate than Michigan, but it has higher costs for culls than Michigan because its yield per hectare is higher than that for Michigan. If the yearly in-field presorting costs (see the following section) are lower than the packinghouse costs for culls that would be saved by in-field presorting, it will be beneficial to fresh apple growers.

Yearly In-field Sorting Costs Estimation

Annual Ownership Costs

Annual ownership costs are calculated using ASABE Standard EP496.3 (*ASABE Standards,* 2006a), assuming 6% annual interest rate, and 2% of initial purchase price for annual taxes, housing, and insurance. A simple estimate of total annual ownership costs is given by multiplying the purchase price of the machine by the ownership cost percentage expressed in decimal form (eq. 1).

$$C_A = P_M \cdot C_0 \tag{1}$$

$$C_0 = \left[\frac{1-S_V}{L} + \frac{1+S_V}{2} i + K_2\right] \tag{2}$$

where

C_A = annual ownership cost;
P_M = machine price;
C_0 = ownership cost percentage, expressed as the machine purchase price in decimal form;
S_V = salvage value factor of machine at end of machine life (year L), decimal;
L = machine life (yr);
i = annual interest rate (decimal); and
K_2 = ownership cost factor for taxes, housing, and insurance;
–Taxes 1.00;
–Housing 0.75;
–Insurance 0.25;
–Total 2.00% of purchase price;

In the analysis, seven year machine life with 10% salvage value was used.

Repair and Maintenance Costs

Expenditures are necessary to keep a machine operable due to wear, part failures, accidents, and natural deterioration. The costs for repairing a machine are highly variable. Good management may keep costs low. Indices of repair and maintenance costs are shown in ASAE D497, clause 6 (*ASABE Standards,* 2006b). The size of the machine, as reflected by its list price and the amount of use are factors affecting the costs. Repair and maintenance costs also vary depending on where services are performed. To reduce the variability, the costs are expressed in accumulated hours of machine use. In times of rapid inflation, the list price must be increased to reflect inflation effects. Accumulated repair and maintenance costs at a typical field speed can be determined with the following relationship using the repair and maintenance factors RF1 and RF2 (ASAE D497, clause 6), the list price and the total use of the machine (hours):

$$C_{RM} = (RF1)P_M \left[\frac{h}{1000}\right]^{(RF2)} \tag{3}$$

where

C_{RM} = accumulated repair and maintenance cost ($);
RF1 and *RF2* = repair and maintenance factors (ASAE D497, clause 6);
P_M = machine list price in current dollars. In times of rapid inflation, the original list price must be multiplied by $(1 + I)^n$ where I is the average inflation rate and n is the age of the machine; and
h = accumulated hours of machine use.

Equation 3 provides an estimate of the total costs of all replacement parts, materials, shop expenses, and labor for maintaining a machine in good working condition. Actual costs may vary widely due to differences in machine maintenance, management, and quality. Again, repair and maintenance factors based upon the accumulated use of the machine are given in ASAE D497, clause 6. Values listed are for machines used under typical field conditions and speeds. These data provide estimates of the average cost for all machines of a given type. Since there are no data for the in-field presorting machine, RF1 = 0.3 and RF2 = 1.6 were chosen based on harvesting machines listed in ASAE D497 table 3 ranging from 0.03 to 0.59 for RF1 and 1.3 to 2.3 for RF2.

Fuel Cost

Average annual fuel consumption for a specific make and model tractor can be approximated from the Nebraska Tractor Test Data (University of Nebraska, 2009). A 22-kW (~30-hp) machine is used for calculating annual fuel cost in this article.

$$Q_{avg} = 0.02126 \cdot W_{PTO} \tag{4}$$

where

Q_{avg} = average gasoline consumption (L/h)
W_{PTO} = maximum PTO power (kW)

Total Yearly In-field Presorting Cost

Based on the above calculations, yearly equipment costs for presorting machines ranging between $20,000 and $40,000 are shown in table 4. The costs shown in table 4 were calculated using ASABE Standard EP496.3 FEB2006. Parameters used to calculate the costs are shown in table 5. The presorting machine was assumed to operate 45 days for each season at 8 h/day. Annual fuel cost was calculated using \$0.66/L (\$2.50/gal). Yearly equipment costs varied from \$6,421 for a \$20,000 machine to \$11,223 with a \$40,000 machine. Labor cost is another important component for the total annual cost for in-field presorting. If in-field presorting requires full-time labor, the cost becomes \$4,320, which is more than 60% of the yearly equipment cost for a \$20,000 machine. Currently, many apple growers use orchard tractors and trailers to assist in apple harvesting (i.e., hauling fruit bins around the orchard), which would require workers to operate. These workers often are also responsible for recording or monitoring the productivity of individual harvest crew members. Hence if an in-field presorting system becomes a part of the existing in-orchard harvest operations, it would require minimal additional labor to operate the system.

Total Revenue Estimation for a Processing Apple Grower with In-field Presorting

In general, processing apple growers do not expect to sell their apples for the fresh market. With adoption of an in-field presorting system, processing apple growers can sell some fresh apples from the apples that are originally destined for processing. Returns for a processing apple grower with in-field presorting were calculated based on the sale prices of \$288/bin (\$16 per 42-lb carton, 18 cartons per bin) for fresh apples and \$90/bin (\$5 per carton, 18 cartons per bin) for processing apples, packinghouse costs of \$126/bin (\$7 per 42-lb carton for packinghouse cost including packaging and sales fee; 18 cartons per bin) for fresh apples and \$50/bin (\$20 CA storage per bin, \$30 grading and sorting per bin) for culls, and \$10/bin for culls storage. The fresh apple and processing apple prices were chosen based on the latest data (2008) available in the Fruit and Tree Nut Yearbook 2009 (USDA 2009b), which reported \$0.39/lb for fresh apple and \$238/short ton for processing apple (average price for canned, frozen, dried, and fresh slices). It should be noted that these prices are subject to change yearly. For the conventional processing apple grower, all apples go for processing under one nondiscriminating pricing schedule (i.e., \$90/bin) regardless of fresh apple rate. Returns for the processing apple growers with in-field presorting are the total value of apples sold as fresh and processing (eq. 5).

$$R_T = R_F + R_P \tag{5}$$

$$R_F = (V_F - C_{PF}) \times b \times r_F \tag{6}$$

$$R_P = (V_P - C_{CS}) \times b \times (1 - r_F) \tag{7}$$

where

R_T = total revenue for processing apple grower with in-field presorting;
R_F = revenue from fresh apples;
R_P = revenue from processing apples;
V_F = value of fresh apples estimated at \$288/bin (\$16/carton);
V_P = value of processing apples, \$90/bin;
C_{PF} = packinghouse cost for fresh apple (CA storage, grading, sorting, packaging and sales fee), \$126/bin (\$7/carton);
C_{CS} = cost of cold storage, \$10/bin;
b = number of bins;
r_F = fresh apple rate;

A typical harvest bin in the United States can contain approximately 363 to 454 kg (800 to 1000 lb) of apples, depending on fruit size and variety. We used 363 kg (800 lb) for each bin to calculate the value of fresh apples and processing apples per bin, so the total revenue estimation in equation 5 would be more conservative.

Table 4. Yearly equipment costs for in-field presorting.

	Equipment Cost (\$)		
Machine Price	20,000	30,000	40,000
Ownership costs	3,631	5,447	7,263
Repair and maintenance costs	1,170	1,755	2,340
Fuel cost	1,620	1,620	1,620
Total equipment cost	6,421	8,822	11,223

Table 5. Parameters used for yearly in-field presorting cost calculations.

Machine Life	7 Years
Salvage	10%
Interest	6%
Operation days	45
Labor	\$12/h
Hours/day	8
Total hours	360
Machine power	22 kilowatt (30 hp)
Fuel	\$0.66/L (\$2.50/gal)

Results and Discussion

Cost Benefits for Fresh Apple Growers

Packinghouse costs for culls saved by in-field presorting for fresh apple growers are shown in table 6. The costs were calculated for 20% and 40% cullage rates for growers with the production scale ranging from 500 bins to 6,000 bins. Required in-field presorting capacities (bins/day) are also listed in the table. Again, the packinghouse costs for culls saved by in-field sorting were calculated based on the assumption that the in-field sorting equipment can sort out 80% of the total cullage apples.

The cost benefits for fresh apple growers were analyzed by comparing total yearly in-field presorting cost including total equipment costs in table 4 and labor cost with the packinghouse cost for culls in table 6. Yearly cost savings for fresh apple growers are shown in figure 4. The in-field presorting machine was assumed to handle 2,000 bins/year (726 MT/year), or 44 bins/day (16 MT/day), which is approximately equivalent to the capacity of a 4 to 5 people harvest crew. We chose this capacity in the analysis because one machine would be sufficient for U.S. average growers (1,768 bins/year or 630 MT/year, 34 bins/acre or 30 MT/ha, 52 acre or 21 ha). Two machines are required to handle 2,000 to 4,000 bins (726 to 1451 MT) and three machines for more than 4,000 bins (1451 MT). Cost savings for machines of \$20,000, \$30,000, and \$40,000, respectively, are shown by the shaded strips of different intensities in figure 4. The upper

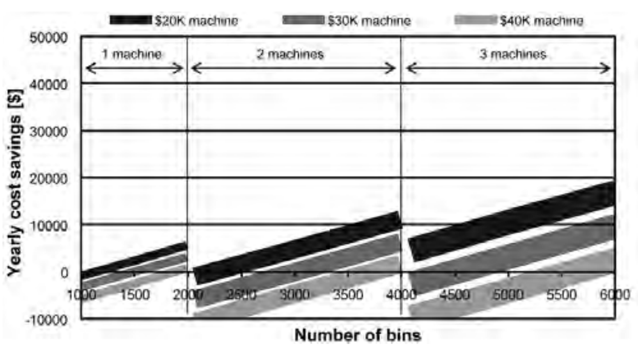
Table 6. Calculated packinghouse cost for culls and required in-field presorting capacities for fresh apple growers.

Bins	Packinghouse Costs for Culls[a]		Required Presorting Capacity (bins/day)[b]
	20% Cullage Rate ($)	40% Cullage Rate ($)	
500	3,200	6,400	11
1000	6,400	12,800	22
2000	12,800	25,600	44
3000	19,200	38,400	67
4000	25,600	51,200	89
5000	32,000	64,000	111
6000	38,400	76,800	133

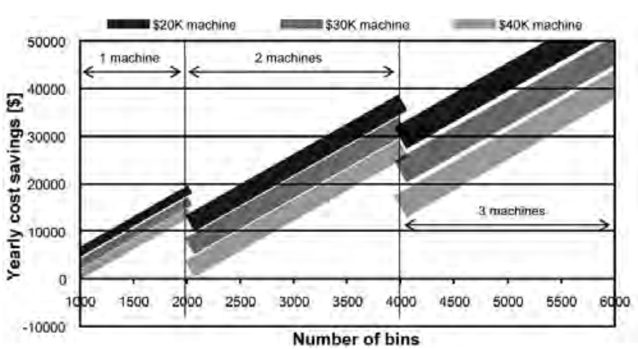
[a] The calculations were based on the assumption that in-field presorting can sort out 80% of cullage apples. Packinghouse cost for culls = ($50-$10) × bins × cullage rate × 0.8, where the cost for CA storage, grading and sorting for culls per bin at the packinghouse was $50 and the cost for cold storage per bin was $10.

[b] The presorting machine was assumed to operate 45 days per season.

bound of each strip represents the cost savings for 0% labor and the lower bound of the strip refers to the cost savings for 30% of a full-time worker. A $20,000 machine with 0% labor can break even for small-size apple growers (<1,000 bins) with 20% cullage rate. A $30,000 machine will be beneficial for growers of more than 1,400 bins, if the cullage rate is 20%. As the machine price increases to $40,000, a minimum of 2,000 bins are needed to break even for 20% cullage rate. If the cullage rate is more than 40%, even a $40,000 in-field presorting machine can be beneficial for small-size fresh apple growers. These results show that cost savings from in-field presorting depend on machinery cost (including labor), farm size, and cullage rate. Growers producing a high percentage of culls will benefit more from in-field presorting.



(a) 20% cullage rate



(b) 40% cullage rate

Figure 4. Yearly cost savings from in-field presorting for fresh apple growers with the cullage rates of (a) 20% and (b) 40% for labor cost ranging from 0% (the upper bound of each shaded strip) to 30% (the lower bound of each shaded strip) of a full-time worker ($12/h).

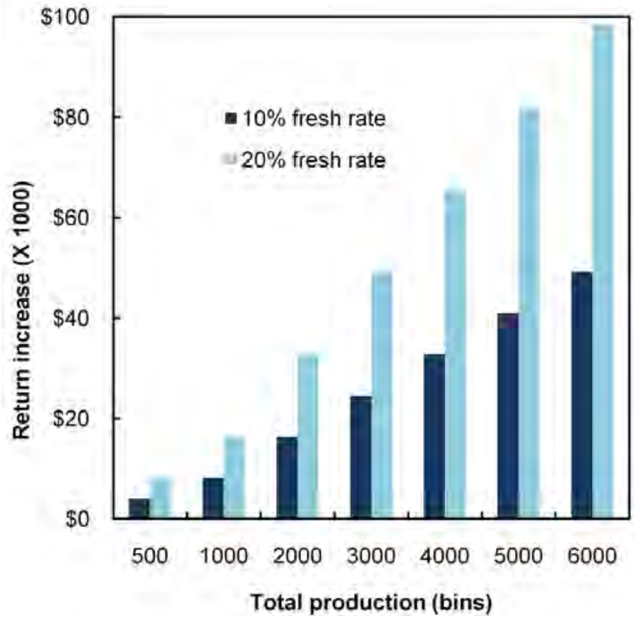


Figure 5. Return increases from an in-field presorting system for processing apple growers.

Cost Benefits for Processing Apple Growers

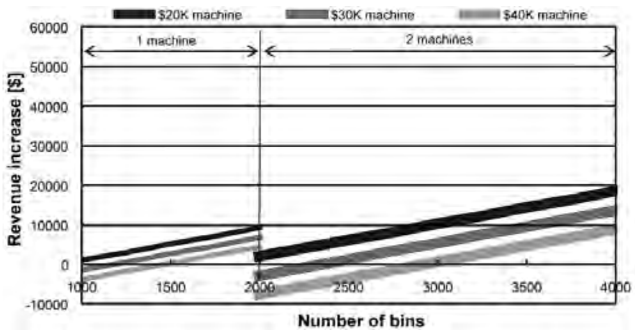
To evaluate cost benefits for processing apple growers, we compared returns for the processing apple grower with and without adoption of in-field presorting for the fresh apple rates of 10% to 20% with the production size ranging from 500 to 6,000 bins.

Increased returns from in-field presorting are shown in figure 5, which are the differences between the revenues with and without adoption of in-field presorting. Clearly, processing apple growers can potentially achieve significant return increases by adoption of an in-field presorting practice, even for 10% to 20% fresh apple rates.

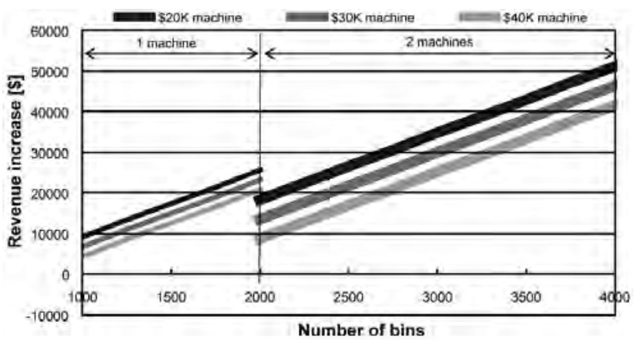
Net revenue increases for 10% and 20% fresh rates are shown in figure 6, which were calculated by subtracting yearly equipment costs for in-field presorting shown in table 4 from return increases from in-field presorting shown in figure 5. The representations of the strips are the same as figure 4. For 10% fresh rate, a machine costing up to $30,000 can be beneficial for small-size growers of about 1,200 bins. Because of large price differences between fresh apples and processing apples, processing apple growers of 700 bin production capacity at a low fresh rate of 20% can gain financial benefit by adopting in-field presorting. These results suggest that processing apple growers would have significant revenue increases by adoption of an in-field presorting practice. Again, the calculations given in figure 6 are subject to change, depending on the relative prices for fresh and processing apples.

Cost Benefits for Packinghouses

Since packing operations differ from packinghouse to packinghouse and no specific data are available on the relationship between packout rate and packing cost, we could only provide qualitative analysis on the cost benefits of



(a) 10% fresh rate



(b) 20% fresh rate

Figure 6. Net revenue increases for processing apple growers with the fresh apple rates of (a) 10% and (b) 20% with the labor cost ranging from 0% (the upper bound of each shaded strip) to 30% (the lower bound of each shaded strip) of a full-time worker ($12/h). (The prices for fresh and processing apples were assumed to be $288/bin and $90/bin, respectively).

in-field presorting for the packinghouse. To improve profitability, packinghouses need to reduce costs per shift or increase per shift productivity. A higher packout rate would mean lower labor cost and thus higher profit for the packinghouse. Conversely, a high cullage rate would lower the productivity (or packout rate) and thus lower profit because the packinghouse receives lower revenue for culls. Adoption of an in-field presorting practice means a lower cullage rate for apples brought to the packinghouse. Therefore, the packout rate and per shift productivity at the packinghouse will be improved by adoption of in-field presorting practices.

Accurate, efficient inventory management is critical to packinghouse profitability. Currently, packinghouses pack specific volumes of apples with specific quality grades for their customers (i.e., wholesalers or retailers). Overpacking or underpacking would mean lower profit for the packinghouse. With no exact prior information about the quality of apples in individual bins, it would be difficult for packers to make optimal decisions on how sorting and grading should be performed. Clearly, if the quality of apples in individual bins (e.g., fruit size, color, maturity, etc.) is recorded during presorting, it would help packers more efficiently manage the inventory to better meet the market requirements.

With adoption of presorting practices, the total volume of apples brought to the packinghouse by fresh apple growers could be reduced due to the removal of culls through presorting. However, this decrease in the total volume of apples could be compensated by an additional volume of apples brought in by processing apple growers, which would otherwise be sold to the processor. Hence, in-field presorting would not negatively impact the packinghouse. On the contrary, the packinghouse can benefit from presorting of apples in the orchard.

Guidelines for Development of In-field Presorting Technology

Based on the cost benefits analysis reported in this article, it seems appropriate to propose some guidelines for the development of in-field presorting technology. As summarized in table 7, the cost of a presorting machine should be no more than $30,000 per unit and the machine should be designed such that it would require minimum additional labor, i.e., no more than 30% of the labor cost for a full-time worker. A single in-field presorting machine should have the capacity of handling 44 bins per day, or 16 metric tons per day for a total of 2,000 bins per season (726 MT per season). Such machine would be beneficial for fresh apple growers having the production capacity of greater than 1,400 bins (or approximately equivalent to 16 ha for the average U.S. grower shown in table 1) for 20% cullage rate, or of 900 bins (or 11 ha) for 40% cullage rate. Processing apple growers producing as low as 700 to 800 bins (approximately 8-9 ha) with a 20% or higher fresh apple rate can also benefit from in-field presorting. For processing apple growers with a 10% fresh apple rate, a minimum production capacity of 1,200 bins is required. In summary, an in-field presorting system that is designed based on these guidelines will benefit not just average U.S. apple growers (21 ha), but also smaller-size growers.

These guidelines are based on current prevailing packinghouse charge schedules and market prices for culls and fresh apples. While these pricing schedules are subject to change, which in turn would change the cost benefits analysis results, the methods reported in this article should still be useful. In this article, we did not consider other intangible benefits (e.g., reduced pest/disease problems, better inventory management, product traceability, etc.) that will be accrued from in-field presorting. When these benefits are taken into account, a presorting machine costing more than the recommended price in this study could still be beneficial for small to average apple growers in the United States.

Table 7. Recommended specifications for in-field presorting machines.

Feature		Description
Price	<	$30,000
Capacity (bins/day)	>	44 bins/day or 16 MT/day
Yearly labor cost	<	30% (or $1,296)
Machine life	>	7 years
Recommended production capacity for fresh apple growers		
20% cullage rate	>	1400 bins (≈ 508 MT or 16 ha)
40% cullage rate	>	900 bins (≈ 327 MT or 11 ha)
Recommended production capacity for processing apple growers		
10% fresh rate	>	1200 bins (≈ 435 MT or 14 ha)
20% fresh rate	>	700 bins (≈ 254 MT or 8 ha)

CONCLUSIONS

In-field presorting can be financially beneficial to small and average fresh apple growers with the production capacity of 1,400 bins (or 508 metric tons) or greater, if the machinery cost is no more than $30,000 per unit. It is, however, important that an in-field presorting system be incorporated as a part of the current fruit harvest and handling operations, so that it will require minimum additional labor to operate. Processing apple growers can gain more benefit if in-field presorting would enable them to sell 10% or more apples to the fresh market that would otherwise be destined for processing. Presorting also has other potential benefits, i.e., reduced pest/disease problems during postharvest storage, better inventory management, higher packout rate, and enhanced product traceability. The economic analysis results presented in this article provide a guide for the development of in-field presorting systems that will ultimately benefit the apple industry.

REFERENCES

ASABE Standards. 2006a. ASAE EP496.3 FEB2006: Agricultural machinery management. St. Joseph, Mich.: ASABE.

ASABE Standards. 2006b. ASAE D497.5 FEB2006: Agricultural machinery management data. St. Joseph, Mich.: ASABE.

Baeten, J., K. Donné, S. Boedrij, W. Beckers, and E. Claesen. 2008. Autonomous fruit picking machine: A robotic apple harvester. In *Field and Service Robotics Results of the 6th Intl. Conf.*, 531-539. C. Laugier, and R. Siegwart, eds. Verlag Berlin Heidelberg: Springer.

Baugher, T., M. Harsh, K. Lesser, J. Schupp, D. Buckmaster, L. Kime, B. Wenk, D. Rice, S. Waybright, J. Van Pelt, R. Musselman, and M. Tindall. 2006. The Penn State Ag innovations initiative: A systems approach for retooling Mid-Atlantic orchards. *Compact Fruit Tree* 39(3): 2-5.

Baugher, T., K. Ellis, J. Remcheck, J. Schupp, H. Ngugi, L. Hull, G. Krawczyk, N. Halbrendt, E. Winzeler, R. Crassweller, R. Marini, J. Harper, L. Kime, P. Heinemann, J. Liu, K. Lewis, G. Hoheisel, V. Jones, M. Glenn, S. Miller, A. Tabb, J. Park, D. Slaughter, S. Johnson, G Reichard, S. Singh, M. Bergerman, G. Kantor and B. Messner. 2010. Specialty Crop Innovations: Progress and Future Directions. Progress Report 2010. Biglerville, Pa.: Fruit Research & Extension Center, College of Agricultural Sciences, Pennsylvania State University. Available at: http://frec.cas.psu.edu/pdf/AgInnovationsDirections0810.pdf Accessed 6 January 2011.

Bollen, A. F., C. P. Riden, and N. R. Cox. 2007. Agricultural supply system traceability: Part I. Role of packing procedures and effects of fruit mixing. *Biosystems Eng.* 98(4): 391-400.

Bulanon, D. M., T. Kataoka, H. Okamonto, and S. Hata. 2004. Feedback control of manipulator using machine vision for robotic apple harvesting. In *Proc. Automation Technology for Off-Road Equipment Conf.*, 91-97. Q. Zhang, A. M. Iida, and A. Mizushma, eds. St. Joseph, Mich.: ASAE.

Bulanon, D. M., T. Kataoka, H. Okamonto, and S. Hata. 2005. Feedback control of manipulator using machine vision for robotic apple harvesting. ASAE Paper No. 053114. St. Joseph, Mich.: ASAE.

Du Brille, J., and B. H. Barritt. 2005. Global apple study: A comparison of costs of production and production practices in eight leading apple-producing countries. *Compact Fruit Tree* 38(1): 6-11.

Faubion, D. 2005. Mechanization of orchard work. *Compact Fruit Tree* 38(3): 5-6.

Giles, D. K., and D. Downey. 2003. Quality control verification and mapping for chemical application. *Precision Agric.* 4(1): 103-124

Hansen, M. 2009. Ready for change. *Good Fruit Grower* 60(17): 36-37.

Moe, T. 1998. Perspectives on traceability in food manufacture. *Trends in Food Sci. & Tech.* 9(5): 211-214.

Qiao, J., A. Sasao, S. Shibusawa, N. Kondo, and E. Morimoto. 2005. Mapping yield and quality using the mobile fruit grading robot. *Biosystems Eng.* 80(2): 135-142.

Riden, C. P., and A. F. Bollen. 2007. Agricultural supply system traceability: Part II. Implications of packhouse processing transformations. *Biosystems Eng.* 98(4): 401-410.

Robinson, T. 2008. The evolution towards more competitive apple orchard systems in the USA. In *Proc. XXVII Intl.* Horticultural Congress - IHC2006: Intl. Symposium on Enhancing Economic and Environmental Sustainability of Fruit Production in a Global Economy, *Acta Horticulturae* 772: 491-500. J. W. Palmer, E. Fallahi, L. Bertschinger, and T. L. Robinson, eds. Seoul, Korea: ISHS.

Schtzko, R. T., and D. Granatstein. 2005. A Brief look at the Washington apple industry: Past and present. Project Report SES 04-05. Pullman, Wash.: School of Economic Sciences College of Human and natural Resource Sciences, Washington State University. Available at: www.agribusiness-mgmt.wsu.edu/AgbusResearch/docs/SES04-05_BRIEF_LOOK_WAFTA.pdf. Accessed 23 December 2009.

Seavert, C. 2005. Economic production model for tree fruit. *Compact Fruit Tree* 38(1): 28-29.

Setiawan, A. I., T. Furukawa, and A. Preston. 2004. A low-cost gripper for an apple picking robot. In *Proc. IEEE Intl. Conf. on Robotics & Automation,* 4448-4453. New Orleans, La.: IEEE.

University of Nebraska, Nebraska Tractor Test Laboratory. 2009. Nebraska and OECD tractor test data for 2009. Lincoln, Nebr.: University of Nebraska.

USDA. 2009a. Census of Agriculture: 2007. United States Summary and State Data Volume 1 Geographic Area Series Part 51. National Agricultural Statistics Database. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf. Accessed 23 December 2009.

USDA. 2009b Fruit and Tree Nuts Yearbook 2009. Economic Research Service Database. Washington, D.C.: USDA Economic Research Service. Available at: www.ers.usda.gov/publications/fts/Yearbook09/FTS2009.pdf. Accessed 9 March 2009.

USDA. 2009c. Noncitrus Fruits and Nuts 2008 Summary United States Summary July 2009. National Agricultural Statistics Database. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: http://usda.mannlib.cornell.edu/usda/nass/NoncFruiNu//2000s/2009/NoncFruiNu-07-08-2009.pdf. Accessed 6 January 2011.

USDOL. 2009. Federal Minimum Wage Rates under the Fair Labor Standards Act, 1938-2009. USDOL Wage and Hour Division Database. Washington, D.C.: U.S. Department of Labor. Available at: www.dol.gov/whd/minwage/chart.pdf. Accessed 24 December 2009.

Warner, G. 2009a. Super-efficient picking system. *Good Fruit Grower* 60(2): 28-29.

Warner, G. 2009b. Field sorting could bring a bonus. *Good Fruit Grower* 60(17): 16.

Wunderlich, L., K. M. Klonsky, and R. L. De Moura. 2007. Sample costs to establish and produce apples. Cost and Return Study Report AP-IR-07. Davis, Calif.: Agricultural & Resource Economics, University of California. Available at: coststudies.ucdavis.edu/files/appleir2007.pdf. Accessed 23 December 2009.

Managing Postharvest Diseases

Dave Rosenberger
Plant Pathologist and Professor Emeritus
Cornell University's Hudson Valley Lab, Highland, NY 12561

Managing fungal diseases that can develop on apples after harvest requires action in at least three arenas during the growing-harvesting season. The risks of postharvest disease development are impacted by sanitation of bins and storages, preharvest fungicide applications, and use of postharvest fungicides (if any).

Sanitation: Research over the past several decades has clearly shown that harvest bins and storage room floors are the major source of inoculum for *Penicillium expansum*, the fungus that causes most of the fruit rots during long-term storage. *P. expansum* survives from one season to the next on storage bins and/or in storage rooms. Spores can remain viable on dry surfaces for several years. In our studies in New York, we found that relatively little inoculum for *P. expansum* originates from orchard sources, but badly contaminated bins can carry more than 900 million *Penicillium* spores per bin from one season to the next.

The spores on bins create problems when filled bins are subjected to recycling drenches containing postharvest treatments because the drench solutions wash spores off of the bins and transfer the inoculum to wounded fruit. It is for this reason that a fungicide must always be included in any recycling drench treatments. However, most of the inoculum on contaminated bins is presumably on the insides of the filled bins where decayed fruit were pressed against the bin surfaces the previous year. That inoculum is not likely to become airborne because the apples in filled bins prevent rapid air movement that would dislodge the spores from the inner bin surfaces. If bins are not run through postharvest drenchers, then the inoculum on the bin surfaces poses a risk primarily to the few wounded fruit that are in direct contact with the contaminated surfaces. No one has found a cost-effective system for sanitizing large quantities of apple bins, so this potential source of inoculum remains uncontrolled and the decay risks associated with contaminated binds is managed primarily by including a postharvest fungicide in any drench solution that is applied to fruit after harvest.

For fruit that are moved to storage without a postharvest drench treatment, the inoculum on bin surfaces will be much less important because most of it will not be dislodged. The greatest source of inoculum for fruit moved directly to storage will probably be airborne spores within the storage room during the time when the room is being filled. All storage rooms should be swept clean and washed out with water to remove any dirt and debris on the floors before the new crop is moved into the rooms. However, cleaning with water will not eliminate the fungal spores from the *Penicillium* species that cause blue mold decay in stored apples. Most apple storage rooms contain at least moderate populations of *Penicillium* spores even after rooms have been swept and washed. The spores survive washing by becoming airborne while the room is being washed, then settling back to the floor when there is no longer any air movement in the room. They remain on the storage room floors until the cooling fans are turned on in the fall, at which time they become airborne again and are available to infect wounds in any freshly harvested apples that are moved into those rooms.

The spore load in storage rooms is best eliminated by applying a sanitizer to the empty storage rooms. Numerous commercial sanitizers are available for applications in apple packinghouses and storage rooms. In the past, quaternary ammonium compounds (quats) were considered the best option for hard surfaces such as bins and storage room surfaces because, unlike chlorine or peroxide type sanitizers, the quats provided significant residual activity. However, the European Union has recently enacted a maximum residue limit of 0.5 ppm for quats (see http://www.nwhort.org/PDFs/DGSANCOBACDDAC.pdf). No one has enough data to know if a quat applied to a storage room floor could be transferred on bin runners in sufficient quantity to generate excessive residues on apples as the bins are lowered into water flotation tanks on grader lines. Because of this uncertainty, storage operators who expect to export apples to the

EU may wish to avoid using quats in their storage rooms or other fruit contact surfaces, at least until more information becomes available.

The extremely low residue limit established by the EU should not be construed as an indication that residues from quats pose a health risk. Rather, it appears that the EU instituted a very conservative residue tolerance primarily because quats have been considered so safe that they have not undergone much testing. The EU uses the precautionary principle of establishing very low limits in situations where companies have not provided a full regimen of safety data.

Other easily-applied biocides that can be used to sanitize storage rooms include peroxides (e.g., Stor-Ox) and chlorinated water. Effectiveness of sanitizers is impacted by the following factors:

1. Product concentration.
2. Temperatures of the solution or surface to be treated.
3. Exposure time.

The limiting factor for the non-quat sanitizers is usually exposure time because activity of these sanitizers ceases as soon as treated surfaces dry (and even before that if surfaces are still dirty). The product labels usually limit product concentrations that can be used. Sanitizers are more active at higher temperatures than at lower temperatures, so storage rooms should be as warm as possible when sanitizers are applied. Exposure time for a 5-log kill with chlorinated water may be less than a minute at 70 °F but more than 10 minutes at 40 °F. Exposure time for peroxide solutions such as Stor-Ox can be extended by having a service company use a fog generator to continuously supply fresh product over a multi-hour period in closed, empty storage rooms.

If rooms are not sanitized using either a quaternary ammonium treatment or via fogging with a sanitizer, then the next best option may be to treat the storage room floor with chlorinated water. We are testing effectiveness of this procedure in several storage rooms right now, but results will not be available in time to make decisions for this season. In the absence of better information, I suggest the following method for storage rooms that will be sanitized by applying chlorine to the floor:

1. The storage room should be at ambient temperature.
2. The door should be closed with the fan off for at least 24 hours before treatment to ensure that all airborne spores will settle to the floor.
3. A labeled chlorine-based sanitizer should be mixed according to label directions, most of which allow for a solution containing 200 ppm of free chlorine.
4. The pH of the chlorine solution should be adjusted to 6.5 since high pH will make the chlorine solution less active and low pH will result in off-gassing of chlorine that can be harmful to the applicator.
5. The chlorine solution should be applied to the storage room floor using a low-pressure sprayer (e.g., a 3-gal backpack sprayer) while taking care to avoid any air turbulence that would cause spores to become airborne. Thus, begin spraying near the door and progress to the rear of the storage while spraying enough chlorine to wet the floor. Walking only on surfaces that have already been wetted will minimize the probability that walking on the dry floor will cause spores on the floor to disperse into the air.
6. Allow the room to dry slowly (or remain wet) for 24 hours before opening the door and turning on the fans to dry the room and dissipate any chlorine odor.

Applying chlorinated water to the floor will NOT eliminate inoculum on the storage room walls, but we know from previous trials that most inoculum settles to the floors in still air. Nevertheless, effectiveness of treating only floors may be reduced in rooms that have blown-in foam on the walls because the uneven surfaces will provide more surface area for spores to settle than would be present on a smooth-surface wall.

Sanitizing storage room floors is probably not essential where postharvest fungicides (Penbotec or Scholar) will be applied to fruit. Nevertheless, any reduction in the inoculum load will reduce selection pressure for resistance to the fungicides that are used in postharvest treatments.

Remember that all sanitizers are somewhat corrosive, so allowing a sanitizer to pool on upper surfaces of fan boxes or other metal components within storage rooms may lead to increased rusting over time. Much more research is needed to document effective sanitation practices, but there are currently very few scientists investigating storage and packinghouse sanitation.

Controlling postharvest diseases via field sprays: Postharvest diseases that must be controlled via field sprays include apple scab (which can appear as pinpoint scab after harvest), sooty blotch and flyspeck (SBFS), and fruit rots caused by *Botryosphaeria* species (black rot, white rot) and *Colletotrichum* species (bitter rot). Pinpoint scab can develop during storage if the orchard has a high incidence of leaf scab, fungicide residues are depleted before harvest, and fruit remain wet for more than 24 hours after the fungicide residues are depleted. Although 24-hr preharvest wetting periods can result in a low incidence of pinpoint scab, severe outbreaks are usually limited to fruit exposed to a 48-hr wetting period shortly before harvest and after fungicide residues were depleted. Fungicide residues are generally depleted after fruit have been exposed to two inches of accumulated rainfall following the application. Fruit infections that occur shortly before harvest will not yet be evident when fruit are harvested, but they will develop into pinpoint scab while fruit are held in cold storage.

Late-season infections by the fungi causing SBFS may also be invisible at harvest and develop during storage if fruit are cooled slowly. Unlike the apple scab fungus which can grow slowly at temperatures below 35 °F., the fungi causing SBFS will not grow after fruit are cooled to below 40 or 45 °F. However, if rooms with limited refrigeration capacity are filled quickly, then it may take 7 to 10 days or more for fruit in the center of stacks to cool to below 40 °F. If fruit in a partially filled room cool down at night and then the temperature rises again the next day as additional fruit are added to the room, the colder fruit may "sweat", thereby providing ideal growing conditions for incubating SBFS infections that needed just a few more hours of wetting to develop visible symptoms.

Effective fungicide coverage during July and August is essential for preventing development of summer fruit rots. If bitter rot becomes established in some fruit, then spores from the infected fruit may spread to other fruit and cause incipient infections that will not be visible at harvest. Those incipient infections can develop into fruit decays during storage. Like the fungi causing SBFS, most of the summer rot fungi stop growing when fruit are cooled to below 40 °F, but the rots can develop rapidly if stored fruit are cooled slowly.

Fungicide options for controlling SBFS and summer fruit rots were discussed in earlier articles (see *Scaffolds Fruit Journal* for 24 June and 30 June, 2014). A few additional points are relevant for the late-summer sprays. To the best of my knowledge, none of the diseases mentioned above can be reliably eradicated by fungicides applied after harvest. Thus, if fruit are left unprotected during critical infection periods in late summer and become infected with SBFS, scab, or summer rot fungi, those errors of omission during summer cannot be corrected by applying a postharvest fungicide.

Research at the Hudson Valley Lab over the past 10 years clearly demonstrated that Pristine provide the longest residual control of SBFS, and a combination of Pristine plus Captan has therefore recommended for the last spray of the season for apple cultivars that will be harvested in October. Because that combination was also very effective for controlling bitter rot, it was also recommended for high-value cultivars such as Honeycrisp and SweeTango that can sometimes develop summer fruit rots. However, Pristine may be in short supply this year. Fortunately, results from a trial that we conducted a the Hudson Valley Lab in 2013 indicate that Merivon should perform just as well as Pristine for controlling SBFS and summer fruit rots (Rosenberger et al., 2014). When fruit from the 2013 trial were held in cold storage after harvest, the incidence of decay that developed in stored fruit was also similar for the Pristine and Merivon plots (data not yet published), thereby providing evidence that Pristine's ability to suppress storage decays will be matched by activity of Merivon. Luna Sensation may also perform well in late summer sprays, but it was not included in our 2013 trial, it is not currently labeled in New York, and it has a 14-day preharvest interval whereas Pristine and Merivon both have 0-day PHIs.

Merivon probably should NOT be substituted for Pristine in situations where a fungicide is being applied shortly before or after applications of Harvista (the sprayable form of 1-MCP). Harvista applications require the use of spray oil, and the Merivon label specifically notes that Merivon should NOT be used with oils or other products formulated as emulsifiable concentrates. We don't yet know what degree of separation may be required between applications of Merivon and Harvista, but caution is advised.

Whereas the potential for damaging fruit via sequential applications of Merivon and Harvista is largely unknown, problems everyone should realize by now that Captan and oil are not compatible and should not be applied within 10-14 days (or perhaps even longer) of one another. Normally, we would recommend that Captan should be included in all summer sprays on apples regardless of what other fungicides might be included in the tank mix. However, it appears that an exception may be required in blocks where Harvista will be applied in the next 10 to 14 days (again, we don't know the exact limits). Where Harvista will be applied, the safest bet will be to apply either Pristine or Flint as the sole fungicide in applications prior to or shortly after Harvista has been applied. However, remember that Flint has a 14-day preharvest interval, that Flint must be used at the rate of 3 oz/A for bitter rot suppression, and that the Flint label specifies only four applications per year with a maximum of 11 oz/A/year. An alternative where Harvista will be used might be to apply a combination of Flint-plus-Ziram or Pristine-plus-Ziram, thus substituting Ziram for Captan. However, Ziram can leave a lot of visible residues, and it will match the activity of Captan only if it is applied at nearly full label rates.

In various trials conducted over the years, including the aforementioned trial last year, I have found that although preharvest applications of Pristine can help to suppress storage decays, the preharvest sprays never match the effectiveness of postharvest drenching for controlling blue mold caused by *Penicillium expansum*. The level of storage rot control provided by Pristine when it is applied in preharvest sprays is presumably affected both by the quality of spray coverage and by the amount of rain that occurs between the last application and harvest. Thus, sprays applied one day before harvest should be more effective for suppressing storage decays caused by *P. expansum* than are sprays applied three weeks before harvest. However, even if sprays are applied one day before harvest, complete coverage of the fruit surface will be almost impossible on trees that carry a full crop. By comparison, postharvest drenching ensures complete coverage, and postharvest fungicides that are "fogged" into storage rooms may provide more complete coverage than can be achieved with preharvest sprays.

Despite the fact that preharvest sprays cannot match the efficacy of some postharvest treatments, the slight edge that is provided by preharvest sprays may be good enough for situations where there is little disease pressure for postharvest decays. In general, the incidence of fruit decays is very low if fruit are not wetted after harvest, if fungicide protection was maintained throughout the growing season, and if harvest is well managed (i.e., fruit are harvested at the proper maturity with a minimum of bruising). Using a preharvest spray within a week or two of the planned harvest date also increases the likelihood that harvested fruit will still have enough residue to prevent SBFS, bitter rot, and black rot from growing during the cool-down period after harvest. Furthermore, preharvest sprays may provide fungicide coverage that is equivalent to the bin-top treatments that have been used successfully to apply diphenylamine (DPA) after harvest. DPA applied via bin-top treatments protects all fruit surfaces from storage scald because the volatility of DPA, but postharvest fungicides are less volatile and therefore do not protect all fruit surfaces when applied as bin-top treatments (Rosenberger, 2011).

One final note: When the QoI fungicides (FRAC group 11) were first labeled, all products in this group (including Flint, Sovran, Pristine) had a label restriction dictating a maximum of four sprays per season for any combination of products that contained a QoI active ingredient. That restriction remains on the current labels for Sovran and Flint. However, the labels for Pristine, Merivon, and Luna Sensation have been changed. Those products still have label limitations indicating that no more than two sprays can be applied in succession with a maximum of four applications per year for each product, but they no longer limit users to a maximum of four applications per year for all QoI fungicides combined. Thus, for example, current labels would allow two applications of Merivon prebloom, two applications of Merivon, post-bloom, and two applications of Pristine in preharvest sprays. However, any use of Flint or Sovran during the season would appear to limit apple growers to a maximum of four sprays per year for any and all products that include a QoI fungicide. Limiting total QoI usage to four sprays per year may help to delay resistance development, but options for using five or six sprays per year (e.g., three or four for early-season scab, plus one or two preharvest) could be helpful in some situations and would be feasible if the Sovran and Flint labels were updated to include the same wording currently used for Pristine, Merivon, and Luna Sensation.

Postharvest fungicides: Fungicides labeled for postharvest use on apples include captan, thiabendazole (Mertect 340F), pyrimethanil (Penbotec), and fludioxonil (Scholar). Captan is of limited value for protecting fruit, but there is some evidence that it may act to kill spores that accumulate in recycling drenches, thereby reducing inoculum loads in the drench solutions. The other postharvest fungicides tend to arrest spore germination and/or growth, but spores exposed to the fungicides may still germinate if the fungicide residues are diluted or removed.

Populations of apple storage pathogens are mostly resistant to thiabendazole, so this product is of limited use in most apple storage operations today. No one has determined if storage operators who use pyrimethanil and fludioxonil for 5 or 10 years will see a gradual reduction in the levels of thiabendazole resistance in the populations of *P. expansum* present in their storages. However, until and unless research shows that thiabendazole resistance fades after periods of non-use, we must assume that thiabendazole is of little value for controlling postharvest pathogens.

Repeated and exclusive use of pyrimethanil in postharvest treatments has already led to populations of *P. expansum* that are resistant to pyrimethanil in both Washington State and in Pennsylvania. To preserve the activity of postharvest fungicides, storage operators should alternate between the two remaining effective products, using pyrimethanil to treat all fruit one year and using fludioxonil on all fruit the next year. This strategy will increase the likelihood that resident spores on bins will not be continuously exposed to the same fungicide year after year. Other resistance management strategies include using sanitation measures to keep spore populations on bins and in storage rooms as low as possible.

Postharvest treatments can be applied by drenching bins with fungicide solution in a recycling drencher, by applying limited quantities of fungicide in bin-top treatments after harvest, or by fogging rooms after they are filled. Each option has advantages and disadvantages. Recycling drenches will probably be phased out in the near future because of food safety concerns: The recycling solution could theoretically contaminate huge quantities of fruit if any toxic substance or organism was introduced into the solution. Postharvest treatment solutions that contain DPA cannot be sanitized with oxidants such as chlorine because DPA is an anti-oxidant that would be inactivated by any of the oxidizers that are used to kill pathogens in packinghouse water flumes.

Bin-top treatments are less expensive than drenches or fogging treatments and they eliminate the food safety issues associated with recycling drenches. As noted earlier, they work very well for applications of DPA but do not provide full fungicide coverage for all of the fruit within the bins.

"Fogged-in" fungicide treatments applied to filled storage rooms have proven effective, although long delays between harvest and the application of the fungicide fog may allow *P. expansum* to become so well established in wounds that fogging will not arrest the development of the decay. Thus, fogging will presumably work best in rooms that are filled rapidly and can be fogged within 4 to 5 days after the first fruit are placed in the room. Although I am not aware of any direct comparisons, I suspect that pyrimethanil will have more reach-back activity than fludioxonil because pyrimethanil is more systemic in fruit than fludioxonil.

Although pyrimethanil and fludioxonil are very effective as postharvest fungicides, one must still question whether a postharvest fungicide is actually needed in fruit that are moved to storage without a postharvest drench treatment. As noted earlier, a preharvest spray with Pristine or Merivon can help to reduce the risk of postharvest losses if no postharvest treatment is applied. Similarly, bin-top treatments with one of the postharvest fungicides will protect those fruit that it contacts, but some fruit in the middle and bottoms of bins will be left unprotected. Those wishing to fully minimize the risks of postharvest decays should still plan to use either a postharvest drench or a fungicide fogging treatment.

The biggest risk from not applying any postharvest treatment may be posed by *Botrytis cinerea* rather than from *P. expansum*. *Botrytis* causes gray mold, the fungus that is notorious for causing the “nesting” of decays that occurs when the fungus grows from one apple to another during storage. However, under controlled atmosphere (CA) conditions, *Botrytis* seems incapable of spreading from one apple to another. Instead, apples with gray mold come out of CA storage looking like baked apples that are often still firm enough to survive the brushes on packing lines.

B. cinerea poses a risk for fruit that receive no postharvest treatment because this pathogen can be present as quiescent infections on fruit coming from the field. Although more research is needed, it appears that *B. cinerea* can infect the sepals or other calyx parts of fruit during late bloom or petal fall if wet weather at that time favors such infections. The infections remain quiescent until fruit have been moved into storage. Some fungicides, such as Inspire Super (which contains cyprodinil, a *Botrytis* fungicide) may protect fruit from *Botrytis* infections when applied at late bloom or petal fall, but there is no data to show whether Inspire Super or any other fungicide applied at petal fall or in summer sprays can reduce the incidence of gray mold in storage. .

We know that latent infections of *Botrytis* were well controlled by the combination DPA plus thiabendazole even after thiabendazole was no longer effective against *Penicillium expansum*. Both fludioxonil and pyrimethanil have also been very effective for controlling *Botrytis.*

However, I have seen situations where *B. cinerea* caused more than five percent of fruit to decay during CA storage in fruit lots that received no postharvest treatment. That experience causes me to be cautious about suggesting that fruit can routinely be moved to storage with no postharvest treatment. Nevertheless, many storage operators have, in fact, totally abandoned postharvest fungicide treatments because they have found by experience that postharvest treatments are not essential in their operations.

Literature cited:

Rosenberger, D.A., Meyer, F.W., Rugh, A.L., Feldman, P.M., and Kostina, J. 2014. Post-infection efficacy of fungicides for controlling summer diseases on apples, 2013. Plant Disease Management Reports 8:PF013. Online publication. DOI:10.1094/PDMR08.

Rosenberger, D.A. 2011. Controlling postharvest diseases and disorders of apples with non-recycling drenches. N.Y. Fruit Quarterly 19(2):21-24. On-line at http://www.nyshs.org/fq.php.

REAL-TIME HARVEST MANAGEMENT — EASTERN U.S. — 2014

HARVISTA™ USE RECOMMENDATIONS

Extend your harvest window and see superior quality.

Harvista™ technology is the pre-harvest ripening-control product developed by AgroFresh that brings superior harvest management to the orchard. Harvista can provide a number of significant benefits when used according to the recommendations listed on the reverse.

Harvista™

Dow AgroSciences

Benefits of Harvista™ technology on apples:

The application of Harvista technology allows you to expand your harvest window 7 to 21 days. One or more of the following benefits are provided, depending upon the variety, orchard conditions, fruit maturity and growing practices:

- Pre-harvest fruit-drop control.
- Safe delay of harvest for additional color and fruit size development.
- Maintenance of fruit firmness before and/or after harvest (short-term storage benefits only).
- Slowed starch conversion.
- Delayed and reduced incidence of watercore.
- Greater consistency in maturity for improved storage performance.
- Fewer pick dates required for multiple-pick varieties.

Important considerations:

- This is not the product label. Read and observe directions on product label.
- Severely stressed orchard conditions may reduce the benefits of Harvista technology. Please contact a Harvista Field Horticulturist for more information.
- The effects of Harvista technology will not become apparent until several days following application.
- Combination effects and interactions between Harvista technology and products containing naphthaleneacetic acid (NAA) or ethephon have not been completely evaluated.
- Harvista technology has a 3-day pre-harvest interval (PHI) for apples.
- 12-hour orchard re-entry interval following application. See label for early-entry PPE requirements.

Recommended application guidelines and timing for best harvest-management results:

APPLE VARIETY	OPTIMUM AVERAGE STARCH INDEX[1] AT APPLICATION	APPLICATION TIMING (DAYS PRE-HARVEST)
Gingergold	**1.0 - 2.0**	3-14 Days
Gala	**2.0 - 3.5**	3-14 Days
McIntosh	**3.0 - 4.0**	3-14 Days
Honeycrisp	**4.0 - 5.0**	3-14 Days
Empire	**2.5 - 3.5**	3-14 Days
Jonagold	**5.5 - 7.0**	3-14 Days
Red Delicious	**1.5 - 2.5**	3-14 Days
Golden Delicious	**3.0 - 5.0**	3-14 Days
Idared	**2.5 - 4.5**	3-14 Days
Fuji	**2.5 - 4.5**	3-14 Days

[1] Starch Index scale of 1 to 8 (Generic Starch-Iodine Index Chart for Apples, Cornell Cooperative Extension Info Bull 221). Considerable block-to-block variability in maturity indexes is normal. Therefore, the best application timing may be based upon average readings of similar blocks in your region. Consult local harvest date recommendations. Optimum maturity levels may vary based upon desired outcome.

Please contact a Harvista Field Horticulturist for more information.

For additional information, please refer to the product label.

AgroFresh, Michigan:
Heidi Davey, Phone: 616-745-9379 email: hbdavey@agrofresh.com

AgroFresh, New York/Pennsylvania:
Keith Culver, Phone: 585-738-2189 email: kculver@agrofresh.com

AgroFresh, Eastern Technical Manager:
Ken Silsby, Phone: 716-471-5383 email: ksilsby@agrofresh.com

Harvista™

www.agrofresh.com

Please note: Individual results may vary. AgroFresh cannot guarantee comparable results.

‘Honeycrisp’ Apples…

Dr. Jennifer DeEll
Fresh Market Quality Program Lead
OMAFRA, Simcoe, Ontario

Ministry of Agriculture, Food and Rural Affairs

Ontario

2013 Trials

Experiment 1

Question – Does delayed CA reduce storage disorders?

Experiment 2

Question – Does air flow during storage affect disorders?

DeEll, 2014

‘Honeycrisp’ - 2013

Experiment 1
(Delayed CA)

Conditioning = 4 d at 15-20°C

Delay = air storage at 3°C

CA = 3% O_2 + 1.5% CO_2 at 3°C

8 months

Harvest = Sept. 16

14.7 lb, 14 ppm, 12% SSC, 6.7 starch, 656 mg malic acid , 65% blush

	Soggy breakdown (%)	Internal CO_2 injury (%)	Lenticel breakdown (%)	Storage rots (%)
0 week	12 ^{a}	9 ^{a}	5 ^{a}	8 ^{ab}
2 weeks	14 ^{a}	10 ^{a}	1 ^{b}	11 ^{a}
4 weeks	4 ^{b}	6 ^{a}	2 ^{b}	3 ^{b}
8 weeks	2 ^{b}	2 ^{b}	3 ^{b}	3 ^{b}
	**	****	****	**

No soft scald, 2-6% senescent browning, 1-4% bitter pit
14.2-14.9 lbs, 58-73 ppm IEC, 12.3-12.7% SSC, 468-530 mg malic acid

DeEll, 2014

Soggy breakdown

Senescent browning

'Honeycrisp' - 2013

Experiment 2
(Air Flow)

No conditioning
Air storage at 3ºC
6 months

	Soggy breakdown (%)	Senescent browning (%)	Soft scald (%)	Bitter pit (%)
No flow	5 ^{a}	8 ^{b}	23	5
+ Flow	3 ^{b}	10 ^{a}	23	6
	*	***	NS	NS
M9 (Ireland)	4 ^{c}	23 ^{a}	3 ^{c}	17 ^{a}
M26 (West)	8 ^{a}	2 ^{c}	27 ^{b}	0.3 ^{c}
M7 (East)	1 ^{d}	6 ^{b}	5 ^{c}	3 ^{b}
M106 (Creek)	5 ^{b}	7 ^{b}	56 ^{a}	2 ^{b}
	****	****	****	****

15 lbs, 88-93 ppm IEC, 12.6% SSC, 450-562 mg malic acid (air flow NS)

DeEll, 2014

2012 Trials

Experiment 1

Timing of SmartFresh treatment
applied 1 day or 5 days after harvest /
at the start or end of conditioning (5 days at 10ºC)

Experiment 2

CA storage and SmartFresh
air vs. CA, +/- SmartFresh

DeEll, 2014

Summary article in workshop proceedings…

Timing of SmartFresh treatment

•Lenticel breakdown was significantly less in apples treated with SmartFresh at 1 day after harvest (2%), compared to those treated 5 days (8%) or not treated (10%)

•Greasiness was reduced consistently with SmartFresh 1 day after harvest, compared to non-treated fruit

•After 6 months of storage, apples treated 1 day after harvest were firmer (+ 0.8-0.9 lb) than those not treated

•When bitter pit was present it was exacerbated in severity by SmartFresh treatment 1 day after harvest

DeEll, 2014

Summary article in workshop proceedings…

CA Storage and SmartFresh

•CA fruit had lower IEC, less greasiness, and fewer cracked fruit than those held in air

•SmartFresh-treated fruit stored in CA were essentially free of greasiness and had the highest malic acid content

•Internal CO_2 injury (5-9%) was found in CA-stored fruit and SmartFresh had no effect on its incidence

•Low incidence of soft scald (1-5%) with no consistent effects of CA or SmartFresh on this disorder

•Summary = CA storage can substantially reduce greasiness in 'Honeycrisp', but there is the added risk of internal CO_2 injury

DeEll, 2014

Key conclusions from other trials…

- **Conditioning** at 10°C for 5-7 days reduces soft scald
- >10°C reduces acidity (physical and sensory) and promotes bitter pit
- **CA storage** not currently recommended
- Limited success using 3% O_2 and 1-1.5% CO_2 at 3°C
- CA tends to reduce soft scald and *earthy/oxidized* flavors
- 'Honeycrisp' is very sensitive to CO_2
- **SmartFresh** reduces greasiness and *earthy/oxidized* flavors, and maintains higher acidity and soluble solids

Sensory article in workshop proceedings…

DeEll, 2014

Specific weather during certain growth stages tends to promote soft scald development…

(Lachapelle et al., 2013)

Full bloom to 10 mm diameter
- wet conditions (>0.5 mm ppt)
- cool conditions (<15°C)

10 mm to 50% of final size
- wet conditions (>6 mm ppt)

50% to 80% of final size
- warm conditions (>20°C)

Specific weather during one growth stage tends to promote soggy breakdown development…

3-4 weeks before harvest
- wet conditions (>0.5 mm ppt)
- cool conditions (<15°C)

DeEll, 2014

Acknowledgements / Collaborators

Ontario Apple Growers
Norfolk Fruit Growers' Association
Apple Marketers' Association of Ontario
CHC – Apple Working Group
AgroFresh Inc.
Agriculture and Agri-Food Canada
Dr. Gaétan Bourgeois, AAFC
Dr. Amy Bowen, VRIC

Research Assistants –
Behrouz Ehsani-Moghaddam
Lorie Walker

DeEll, 2014

CA Storage and SmartFresh Treatment of 'Honeycrisp'

Dr. Jennifer DeEll, Fresh Market Quality Program Lead, OMAFRA – Simcoe, Ontario

Controlled atmosphere (CA) storage is not currently recommended for 'Honeycrisp' in Ontario, because there tends to be increased risk in CO_2 injury and CA-stress related disorders.

To further evaluate the potential of CA storage for 'Honeycrisp', the following scenario was investigated. Apples were harvested on September 10, 2012 from a commercial orchard near Simcoe, Ontario. Apples were transported to the *Apple Research Storage Lab* in Simcoe, within one hour of harvest. Fruit maturity upon arrival at the lab consisted of 3.8 ppm internal ethylene concentration, 13.6 lb firmness, 13.4% soluble solids concentration, 637 mg malic acid per 100 g of juice, 7.5 starch index (Cornell chart), and 46% red blush.

Following harvest, 12 boxes of 'Honeycrisp' apples were held for 5 days at room temperature, fluctuating around 18^{o}C during the day to 10^{o}C overnight. Six boxes were treated with SmartFresh (1 ppm, 24 hr) at room temperature 1 day after harvest. After the conditioning period of 5 days at room temperature, three boxes treated with SmartFresh and three boxes not treated were moved into air storage and into **CA (3.0% O_2 + 1.5% CO_2)** at 3^{o}C for 6 months.

'Honeycrisp' stored in CA had lower internal ethylene concentrations, less greasiness, and fewer cracked fruit than those held in air storage. Furthermore, SmartFresh-treated fruit stored in CA were essentially free of greasiness and had the highest malic acid content. There were no significant effects of CA and/or SmartFresh on fruit firmness or soluble solids concentration.

Some internal CO_2 injury (5-9%) was found in CA-stored 'Honeycrisp' and SmartFresh had no effect on its incidence. There was low incidence of soft scald (1-5%), with no consistent effects of CA or SmartFresh on this disorder. There were also no consistent effects of CA and/or SmartFresh on bitter pit incidence (4-11%). High incidence of storage rots (13-31%) were found in all treatments.

In summary, CA storage can substantially reduce greasiness in 'Honeycrisp' apples, but there is also added risk of internal CO_2 injury development.

Acknowledgements – financial support for this work was provided by Ontario Apple Growers, Apple Marketers' Association of Ontario, Canadian Horticultural Council Apple Working Group, AgroFresh Inc., and Agriculture and Agri-Food Canada.

Timing of SmartFresh Treatment on 'Honeycrisp'

Dr. Jennifer DeEll, Fresh Market Quality Program Lead, OMAFRA – Simcoe, Ontario

'Honeycrisp' apples are typically held at ~10^{o}C for 7 days before subsequent cold storage at ~3^{o}C. Therefore, the following is a common question – is it better to apply SmartFresh before or after the conditioning period?

To help address this query, 'Honeycrisp' apples were harvested on September 10, 2012 from a commercial orchard near Simcoe, Ontario. Apples were transported to the *Apple Research Storage Lab* in Simcoe, within one hour of harvest. Fruit maturity upon arrival at the lab consisted of 3.8 ppm internal ethylene concentration, 13.6 lb firmness, 13.4% soluble solids concentration, 637 mg malic acid per 100 g of juice, 7.5 starch index (Cornell chart), and 46% red blush.

Nine boxes of apples were held for 5 days at room temperature, fluctuating around 18^{o}C during the day to 10^{o}C overnight. This regime occurs often, when a dedicated room at 10^{o}C is not commercially available for 'Honeycrisp' conditioning. Three boxes were treated with SmartFresh (1 ppm, 24 hr) at room temperature 1 day after harvest. After 5 days, all boxes were moved to air storage at 3^{o}C. Three boxes were then treated with SmartFresh at 3^{o}C, representing treatment at 5 days after harvest. Three boxes were left untreated. All apples were subsequently held for 4 and 6 months in ambient air at 3^{o}C.

There were few differences in 'Honeycrisp' treated with SmartFresh on 1 or 5 days after harvest. Lenticel breakdown was significantly less in apples treated with SmartFresh at 1 day after harvest (2%), compared to those treated at 5 days (8%) or not treated (10%), after 4 months in air storage at 3^{o}C. This trend was also apparent after 6 months of storage, although not statistically significant.

Greasiness was reduced consistently with SmartFresh treatment at 1 day after harvest, compared to non-treated fruit. After 6 months of storage, apples treated at 1 day after harvest were also firmer (+ 0.8-0.9 lb) than those not treated. There were no significant differences in greasiness or firmness in apples treated with SmartFresh at 5 days after harvest or not treated.

When bitter pit was present it was exacerbated in severity by SmartFresh treatment at 1 day after harvest. However, there was no significant difference in bitter pit (incidence or severity) in non-SmartFresh 'Honeycrisp' and those treated at 5 days after harvest. Bitter pit incidence ranged from 9 to 13% and 33 to 37% after 4 or 6 months of storage, respectively.

Regardless of treatment time (1 or 5 days after harvest), 'Honeycrisp' treated with SmartFresh had lower internal ethylene concentration and higher malic acid than fruit not treated. There were no significant effects of SmartFresh on soluble solids concentration, soft scald incidence or storage rots.

Acknowledgements – financial support for this work was provided by Ontario Apple Growers, Apple Marketers' Association of Ontario, Canadian Horticultural Council Apple Working Group, AgroFresh Inc., and Agriculture and Agri-Food Canada.

Effects of 1-Methylcyclopropene and Controlled Atmosphere Storage on the Quality of 'Honeycrisp' Apples

J.R. DeEll and B. Ehsani-Moghaddam
Ontario Ministry of Agriculture
Food and Rural Affairs
Box 587, Simcoe, ON, N3Y 4N5 Canada

A.J. Bowen and I. Lesschaeve
Vineland Research and Innovation Centre
Vineland Station, ON, L0R 2E0 Canada

Keywords: *Malus* ×*domestica*, CA, disorders, flavor, texture, 1-MCP, sensory evaluation

Abstract

The objective of this study was to investigate the effects of 1-methylcyclopropene (1-MCP) and controlled atmosphere (CA) storage on the physical and sensory quality of 'Honeycrisp' apples during storage. Fruit were harvested from a commercial orchard, treated with or without 1-MCP (1 µL L^{-1}) for 24 hours at 8-10°C, held for 5 days at 10°C, and then stored at 3°C in air or CA (3.0 kPa O_2 + 1.5 kPa CO_2) for 8 months. Physical and sensory attributes were evaluated during subsequent holding at room temperature (~22°C) within 1 week. 'Honeycrisp' stored in CA or treated with 1-MCP had lower IEC and higher SSC. Fruit held in CA also had less peel greasiness, while those treated with 1-MCP had higher titratable acidity. The interaction of *1-MCP* × *CA* resulted in inconsistent differences in fruit firmness. Internal CO_2 injury was the most prevalent disorder, with the highest incidence in apples treated with 1-MCP and stored in CA. Sensory evaluations revealed that 'Honeycrisp' treated with 1-MCP had lower perceived intensities of oxidized red apple, earthy flavours, skin thickness and chewy textures than their counterparts without 1-MCP. In addition, apples treated with 1-MCP were rated overall as higher in lemony, fresh green apple flavours and acid taste. Fruit not treated with 1-MCP and stored in air were rated higher for oxidized red apple, earthy flavours compared to all other fruit, while CA-stored apples with 1-MCP were rated the highest for fresh green apple flavour and acid taste.

INTRODUCTION

'Honeycrisp' apple continues to increase in popularity and production due to its outstanding flavour and uniqueness in remaining firm during storage. However, flavour is not always consistent and there is risk of developing several physiological disorders. In addition to its inherent susceptibility to soft scald, soggy breakdown, and senescent browning, 'Honeycrisp' is also sensitive to CO_2 and CA-related disorders (DeEll, 2010; DeEll and Ehsani-Mogghaddam, 2010; Moran et al., 2010; Tong and Mader, 2009; Watkins and Nock, 2012; Watkins et al., 2004). The objective of this study was to investigate the effects of 1-methylcyclopropene (1-MCP) and controlled atmosphere (CA) storage on the physical and sensory quality of 'Honeycrisp' apples during storage.

MATERIALS AND METHODS

Plant Material

'Honeycrisp' apples (*Malus ×domestica* Borkh.) were harvested on September 16, 2011 from a commercial orchard near Simcoe (Norfolk County) Ontario, Canada. There were 12 boxes (~ 18 kg of fruit per box) and each box contained fruit from several trees and various locations within the trees.

Postharvest Treatments

Apples were transported immediately following harvest to the nearby storage research facility and cooled overnight at 8-10°C. Half of the boxes were then placed in an air-tight treatment tent (Storage Control Systems Inc., Sparta, MI) and exposed to 1 $\mu L\ L^{-1}$ 1-MCP (SmartFresh[SM], AgroFresh Inc., Spring House, PA) for 24 hours. The 1-MCP concentration was calculated according to the percent active ingredient and release from SmartFresh tablets into the volume of the tent.

Following 1-MCP treatment, all apples remained at 10°C for a total of 5 days. Subsequently, three boxes (replicates) with 1-MCP and three boxes without were placed into CA storage (3.0 kPa O_2 + 1.5 kPa CO_2) or held in air storage at 3°C for 8 months.

The CA system consisted of small aluminium storage chambers (0.9 m^3 volume) fitted with a circulating fan system (Storage Control Systems, Sparta, MI). Atmospheres were checked hourly and maintained within 0.2 kPa of target values using an ICA 61/CGS 610 CA Control System (International Controlled Atmosphere Ltd., Kent, UK), which was modified with flow controllers for the experimental chambers (Storage Control Systems, Sparta, MI).

Fruit Quality Evaluations

Initial fruit maturity at the time of harvest was evaluated on two 10-apple samples. Internal ethylene concentration (IEC) was determined by withdrawing a 3-mL gas sample from the core of each fruit using a syringe and injecting the sample into a Varian CP-3800 gas chromatograph (Varian Canada Inc., Mississauga, ON) equipped with a 0.5-mL sample loop, flame ionization detector (FID), and 15 m × 0.32 mm Restek Rt-SPLOT™ capillary column (Chromatographic Specialties Inc., Brockville, ON).

Fruit firmness was determined on opposite sides of each apple after peel removal, using an electronic texture analyzer fitted with an 11-mm tip (GÜSS, South Africa). Titratable acidity (expressed as mg equivalents of malic acid per 100 mL of juice) was determined by titrating a 2-mL juice sample with 0.1 N NaOH to an endpoint of pH 8.1 (as indicated by phenolphthalein) and soluble solids concentration (SSC) was determined using a digital refractometer (PR-32, Atago Co., Ltd, Japan). Starch content was determined using the Cornell Starch Chart (Blanpied and Silsby, 1992). Apples were cut in half at the equator and rated on a scale of 1 to 8, where 1 = 100% starch staining and 8 = 0% staining.

After 8 months of storage plus 1 and 7 days at ~22°C, five fruit per replicate (box) of each treatment were measured for IEC and ten fruit for firmness, SSC, and titratable acidity. The incidence of storage disorders and rots were determined after 7 days, using ~55 apples per replicate of each treatment. Incidence was calculated as a percentage of fruit with the disorder or rot, regardless of severity. Percentages were arcsine transformed for data analyses.

Data were analyzed by generalized linear models procedures using the SAS program (version 9.1.3, SAS Institute Inc., Cary, NC). Mean separations were examined using Duncan's Multiple range test and only differences significant at $P \leq 0.05$ are discussed.

Sensory Evaluations

After removal from storage, 'Honeycrisp' apples were held at room temperature (22-24^{o}C) for 5 days before sensory analyses. Apples were rinsed with cool, filtered water, 30 minutes prior to evaluation. At the time of presentation, apples were cut into eight uniform wedges with an apple slicer and immediately distributed. All evaluations were conducted in the Vineland Sensory and Consumer Research Laboratory under red lights to minimize visual cues.

Assessors participated in one 30-minute session and performed two triangle tests following the ASTM guidelines 1885-04 (ASTM, 2000). For each triangle test, assessors received one apple wedge (with the skin) in a three-digit coded, two-ounce plastic cup. 1-MCP treatment was first examined; 26 subjects (17 females and 9 males) evaluated 1) Air storage with 1-MCP vs. without 1-MCP, and 2) CA storage with 1-MCP vs. without 1-MCP. Storage regime (Air or CA) was also examined; 11 subjects (9 females and 2 males) evaluated 1) Air storage with 1-MCP vs. CA with 1-MCP, and 2) Air storage without 1-MCP vs. CA without 1-MCP.

Descriptive analysis (DA) was performed to determine differences and similarities among the sensory properties of the apples. Ten members of the trained Vineland sensory panel (8 females and 2 males) participated in the evaluations. An 18 attribute apple sensory lexicon was developed through consensus of the panel members. This consisted of sweet, acid, bitter and astringent tastes; earthy, hay, lemony, honey, floral, fresh red apple, fresh green apple, and oxidized red apple flavours; and texture as skin thickness, crispness, juiciness, chewiness, mealiness, and rate of melt. For each apple treatment, assessors rated their perceptions on 15 cm line scales, calibrated with the reference standard intensity, and anchored from "weak" to "intense". For each sample, two apple wedges (with the skin) were presented one-by-one in three-digit coded two-ounce plastic cups according to a Williams Latin Square design. Assessors were instructed to take one bite for rating flavour and taste attributes, and another bite for rating the texture attributes. Each apple treatment was assessed in duplicate during a 90-minute session. Treatments were randomly assigned to flights and profiled with a 15-minute break after four samples to avoid sensory fatigue. Assessors were provided with filtered water and unsalted crackers to cleanse their palate and encouraged to take breaks between samples. Data were collected electronically using the sensory software EyeQuestion® (Logic 8, the Netherlands) and was analyzed with XLStat® (Addinsoft, France).

The DA data was analyzed by 2- and 3-factor Analysis of Variance (ANOVA). A 3-factor mixed model ANOVA (storage condition, assessor and replicate), with interaction between storage condition and assessor was run to test repeatability of the assessors for each attribute. While the 2-factor mixed model ANOVA (storage condition and assessor) with interaction was used to report the differences between treatments.

Principal components analysis was conducted on the profiling data using the covariance matrix for the "discriminating attributes"; attributes for which there was a significant storage condition effect ($p<0.05$).

RESULTS AND DISCUSSION

Apples were harvested within the commercial harvest window. 'Honeycrisp' fruit at the time of harvest averaged 72 N firmness, 19.5 $\mu L\ L^{-1}$ IEC, 13.1% SSC, 771 mg malic acid per 100 mL of juice, 6.4 starch index, and 62% red blush. This is typical maturity of 'Honeycrisp' destined for storage.

After 8 months of storage, apples from CA storage had lower IEC, higher SSC, and less peel greasiness (Table 1). 1-MCP-treated apples had lower IEC, and higher SSC and titratable acidity. There were no significant main effects of CA or 1-MCP on firmness (data not presented). However, the interaction of *1-MCP* × *CA* resulted in inconsistent differences in fruit firmness (Table 1).

Triangle tests by the sensory panel revealed no significant differences associated with 1-MCP, but Air vs. CA-stored apples were found significantly different with or without 1-MCP. *Descriptive analysis* profiling data showed apples were different for seven attributes (Figure 1). Apples treated with 1-MCP had lower perceived intensities of oxidized red apple, earthy flavours, skin thickness and chewy textures than their counterparts without 1-MCP. In addition, apples treated with 1-MCP were rated overall as higher in lemony, fresh green apple flavours and acid taste. Air-stored apples without 1-MCP were rated higher for oxidized red apple, earthy flavours compared to all other fruit, whereas CA-stored apples with 1-MCP were rated the highest for fresh green apple flavour and acid taste.

Previous sensory results found that 1-MCP-treated 'Honeycrisp' rated higher for acid taste and lower for unfavorable off-flavors during air storage (DeEll et al., 2011). Lower ethanol concentrations have been found in 'Honeycrisp' treated with 1-MCP (Watkins and Nock, 2012).

Internal CO_2 injury was the most prevalent disorder, with the highest incidence in 'Honeycrisp' treated with 1-MCP and stored in CA (Table 2). Previous work showed that 1-MCP exacerbated internal CA-related disorders in 'Honeycrisp' (DeEll, 2010). Similarly, Watkins and Nock (2012) also found that 1-MCP treatment sometimes increased internal CO_2 injury in 'Honeycrisp', especially if applied soon after harvest.

Although the incidence of soft scald was low (<5%), apples treated with 1-MCP and held in air storage had more than those not treated with 1-MCP and held in CA (Table 2). Negative relationships between soft scald and IEC or peel greasiness have been found in 'Honeycrisp' (Ehsani-Moghaddam and DeEll, 2013). There was also low incidence of bitter pit in the current study, but neither CA nor 1-MCP affected its development. Apples stored in CA had the highest amounts of storage rots. This was likely due to limited air flow within the CA chambers.

CONCLUSIONS

Differences in 'Honeycrisp' fruit quality associated with CA storage or 1-MCP treatment were detected by physical measurements as well as through sensory evaluations. Therefore, postharvest handling or storage regimes that affect specific fruit quality attributes (i.e. acidity, SSC, off-flavors) can ultimately influence consumer satisfaction with ‘Honeycrisp’ apples.

ACKNOWLEDGEMENTS

Thanks to AgroFresh Inc., Ontario Apple Growers, Norfolk Fruit Growers' Association, Agriculture and Agri-Food Canada, and the Canadian Horticultural Council for their support to this project.

Literature Cited

American Society for Testing and Materials (ASTM). 2000. ASTM-E1885-04 Standard test method for sensory analysis – Triangle Test. July 2013 *http://www.astm.org/Standards/E1885.htm*

Blanpied, G.D. and Silsby, K. 1992. Predicting harvest date windows for apples. Cornell Univ. Info. Bul. 221.

DeEll, J. 2010. SmartFresh and storage of 'Honeycrisp' apples'. 53rd Intl. Fruit Tree Assoc. Conference. Compact Fruit Tree 43(1):20-23.

DeEll, J.R. and Ehsani-Moghaddam, B. 2010. Preharvest 1-methylcyclopropene treatment reduces soft scald in 'Honeycrisp' apples during storage. HortScience 45:414-417.

DeEll, J.R., Lesschaeve, I. and Mattheiu, N. 2011. SmartFresh^{SM} technology, 'Honeycrisp' apples. Factsheet. AgroFresh, Inc. 2 pp

Ehsani-Moghaddam, B. and DeEll, J.R. 2013. Relationships among ripening attributes and storage disorders in 'Honeycrisp' apple. Fruits 68:1-8.

Moran, R.E., DeEll, J.R. and Murr, D.P. 2010. Effects of preconditioning on the occurrence of postharvest storage disorders in 'Honeycrisp' apples. HortScience 45:1719-1722.

Tong, C. and Mader, E. 2009. 'Honeycrisp' apple research results. Northeast regional postharvest of fruit project 1036. July 2013 *http://smfarm.cfans.umn.edu/Honeycrisp.htm*

Watkins, C.B. and Nock, J.F. 2012. Controlled-atmosphere storage of 'Honeycrisp' apples. HortScience 47:886-892.

Watkins, C.B., Nock, J.F., Weis, S.A., Jayanty, S. and Beaudry, R.M. 2004. Storage temperature, diphenylamine, and pre-storage delay effects on soft scald, soggy breakdown and bitter pit of 'Honeycrisp' apples. Postharvest Biol. Technol. 32:213-221.

Tables

Table 1: Fruit quality of ‘Honeycrisp’ apples treated with or without 1-MCP and held in air or CA (3.0 kPa O_2 + 1.5 kPa CO_2) storage at 3°C for 8 months.

	Firmness (N)	IEC ($\mu L\ L^{-1}$)	SSC (%)	Malic acid (mg/100 mL)	Peel greasiness (1-3)
1 Day at ~22°C					
Air					
No 1-MCP	74.7 ^{BC}	76 ^{C}	14.0 ^{B}	816 ^{B}	3 ^{A}
+ 1-MCP	75.2 ^{BC}	47 ^{D}	15.4 ^{A}	939 ^{A}	3 ^{A}
CA					
No 1-MCP	73.8 ^{C}	38 ^{D}	14.1 ^{B}	648 ^{D}	2 ^{B}
+ 1-MCP	68.0 ^{D}	1 ^{E}	15.5 ^{A}	726 ^{C}	2 ^{B}
7 Days at ~22°C					
Air					
No 1-MCP	74.3 ^{C}	179 ^{A}	13.7 ^{B}	481 ^{F}	3 ^{A}
+ 1-MCP	77.9 ^{AB}	137 ^{B}	14.5 ^{B}	592 ^{E}	3 ^{A}
CA					
No 1-MCP	76.5 $^{A-C}$	137 ^{B}	14.0 ^{B}	581 ^{E}	3 ^{A}
+ 1-MCP	79.7 ^{A}	32 ^{D}	16.1 ^{A}	760 ^{C}	3 ^{A}
Significance [1]					
CA	NS	****	*	*	****
1-MCP	NS	****	****	****	NS
CA × 1-MCP	NS	****	****	NS	****
CA × 1-MCP × Day	****	****	****	****	****

[1] **** = significant at P<0.0001; means within each column with the same letter are not significantly different at P≤ 0.05

Table 2: Disorders and storage rots in 'Honeycrisp' apples treated with or without 1-MCP and held in air or CA (3.0 kPa O_2 + 1.5 kPa CO_2) storage at 3^{o}C for 8 months, plus 7 days at ~22^{o}C.

	Soft scald (%)	Bitter pit (%)	Internal CO_2 injury [1] (%)	Storage rots (%)
Air				
No 1-MCP	2.7 ^{AB}	4.0 ^{A}	0 ^{C}	4.0 ^{C}
+ 1-MCP	4.8 ^{A}	2.1 ^{A}	3.2 ^{C}	4.7 ^{BC}
CA				
No 1-MCP	0.6 ^{B}	3.3 ^{A}	12.2 ^{B}	10.8 ^{A}
+ 1-MCP	3.0 ^{AB}	2.2 ^{A}	34.4 ^{A}	9.4 ^{AB}
Significance [2]				
CA	NS	NS	****	***
1-MCP	NS	NS	****	NS
CA × 1-MCP	*	NS	****	*

[1] Internal CO_2 injury did not always have well defined cavities.
[2] NS, *, ***, **** = not significant or significant at $P<0.05$, $P<0.001$ or $P<0.0001$, respectively; means within each column with the same letter are not significantly different at $P\leq 0.05$.

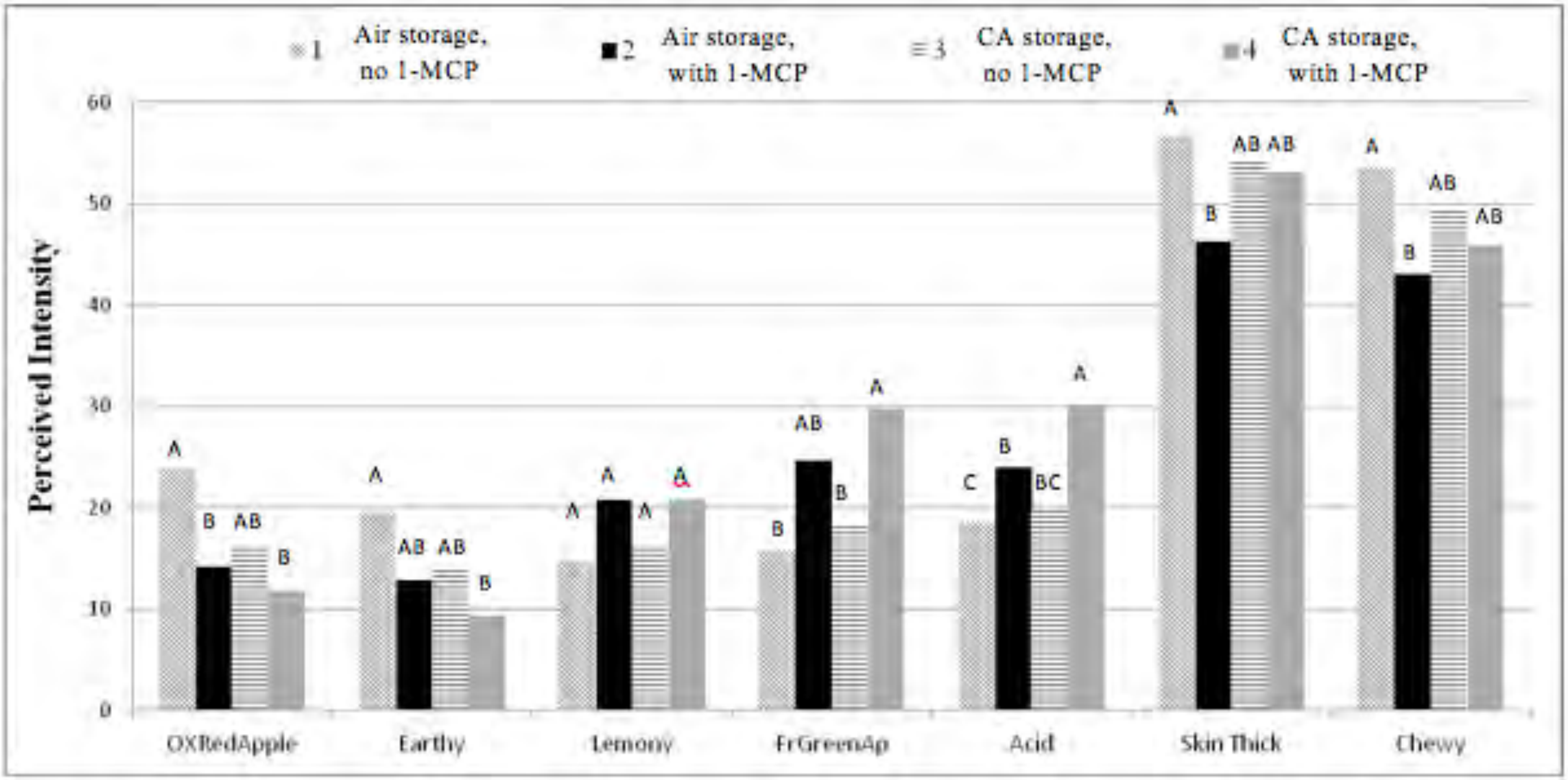


Fig. 1. Perceived intensity of significant attributes (p<0.05) describing 'Honeycrisp' apples treated with or without 1-MCP and stored in Air or CA. Attributes with the same letter are not significantly different.

‘Honeycrisp’ – New York

Chris Watkins
Department of Horticulture
Cornell University
Chris.watkins@cornell.edu

HC is susceptible to a number of physiological disorders, many related to maturity

- Bitter pit
- Soft scald

and Soggy breakdown

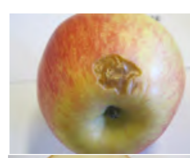
- Blotch-like

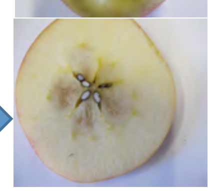
necrosis

- Skin wrinkling
- Blotch-like necrosis
- Internal CO_2 injury

-core browning

Senescent bkdn





New York focus

- Air storage
  - Regional effects and bitter pit vs soft scald risk
- CA storage
  - DPA and delayed CA to control CO_2 injury

Part 1. Air storage

Honeycrisp – Western NY 2013 effect of conditioning Soft scald (%)

	WNY-1	WNY-2	PA
33F	22a	28a	8a
33F + conditioning	3b	3b	6a
38F	0.3b	0b	0b
38F + conditioning	0b	0b	0b

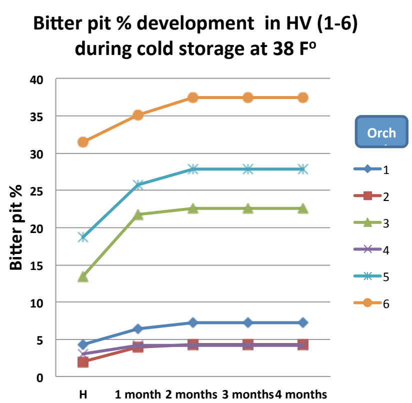
Honeycrisp – Western NY and PA 2013 effect of conditioning Bitter pit (%)

	WNY-1	WNY-2	PA
33F	5c	2b	4b
33F + conditioning	8bc	2b	24a
38F	13ab	3b	5b
38F + conditioning	20a	5a	28a

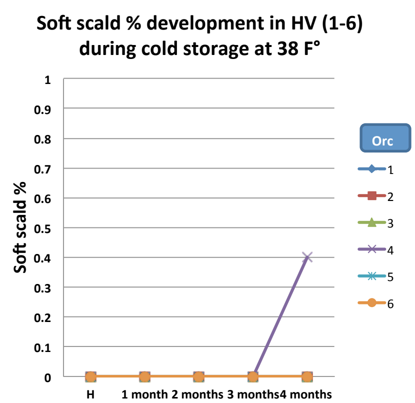
AVOIDING CONDITIONING – STRATEGY FOR SOME GROWING REGIONS

Hudson Valley

Bitter pit

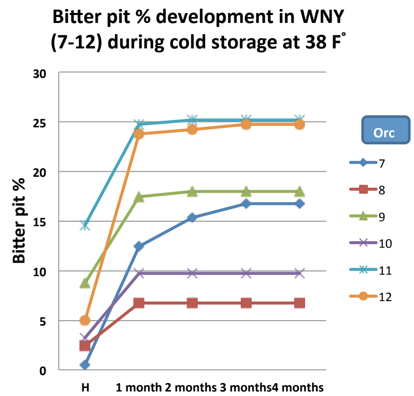


Soft scald

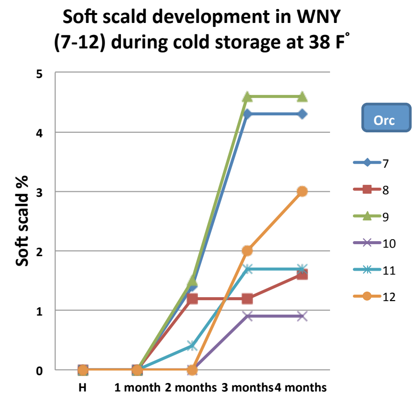


Western NY

Bitter pit



Soft scald



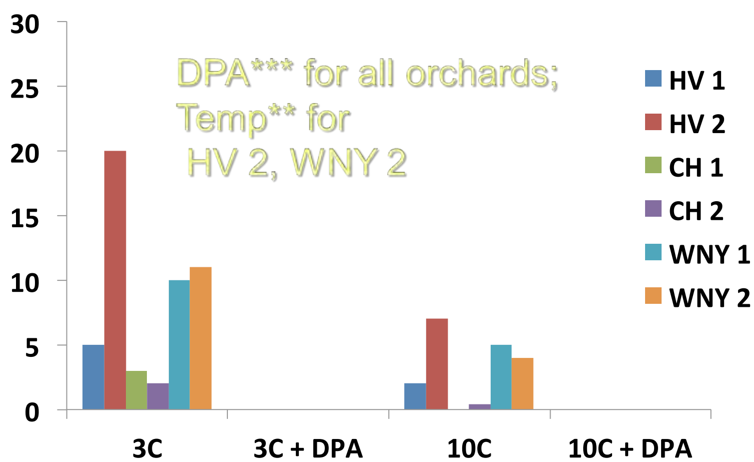
Summary – air storage

- Regional effects significant – 'in general', soft scald risk is low in HV, high in Champlain, with WNY intermediate; bitter pit the reverse
- SmartFresh recommended for longer term air storage – can help maintain higher SSC and TA , and reduce greasiness for short term storage
- Considering changing recommendation for HV and other regions to not condition fruit, but store directly to reduce bitter pit risk
  - Prediction methods being developed

Part 2. CA storage

DPA and delayed CA to control CO_2 injury

% Internal CO_2 injury after storage



38F 38F + DPA 50F 50F + DPA

Decay after storage

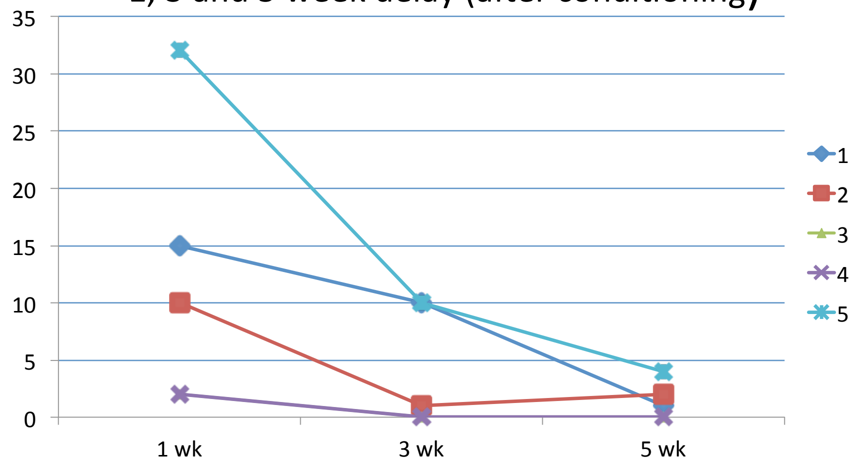
Ranged from 4 to 90%! Though generally not as extensive as the slush bucket!

Summary

- **DPA provides a powerful tool to prevent internal carbon dioxide injury of 'Honeycrisp' apples, but serious concerns about decay in this cultivar**
  - **No fungicide was used**
  - **Fruit were treated on day of harvest and wounding of this thin skinned cultivar with rigid stems is a concern**
  - **Delaying DPA treatment might allow wound sites to heal**
  - **Alternative methods of applying DPA need to be explored**
    - **Non recycling drenches**
    - **Thermofogging**
    - **Aerosol**

CO_2 injury after CA (3%/3%) storage for 6 m

- 1, 3 and 5 week delay (after conditioning)



Negligible soft scald, little effect on bitter pit, small increase in greasiness

Delayed CA: Summary

- Seems like effective means of maintaining quality in CA with low CO_2 injury risk
- Quality as judged by firmness, acidity, SSC is not compromised
- Extended to other growing regions

The people and the funding

The people

Yosef Al-Shoffe
Jackie Nock
Tara Baugher

Growers and storage operators

- JD Fowler
- Jeff Crist
- Seth Forrence
- John Russell
- Adam Sullivan
- Roger Bannister

The funding

NY Apple Research Development Program

AgroFresh Inc.

NYFVI

Valent Biosciences

Federal Funds Project NE1036

Toward Optimizing CA Storage of Honeycrisp Apples: Minimizing Prestorage Conditioning Time and Temperature

R.M. Beaudry, Horticulture
E-mail: beaudry@msu.edu
Department: Horticulture
Mail Address: A288 Plant and Soil Sci. Bldg

Team Members
Carolina Contreras and Diep Tran, MSU Department of Horticulture
with the cooperation of Philip Schwallier, Robert Tritten, Bill Shane, Amy Irish-Brown, Mira Danilovich, and Nikki Rothwell)

The Honeycrisp apple continues to be a popular and valuable addition to the varietal mix of apples grown in the U.S. Significant production acreage can now be found in Michigan, Minnesota, New York, Nova Scotia, Ontario, and Washington. Honeycrisp is one of the most profitable apples grown on a per fruit basis and the number of bearing acres is increasing dramatically each year. As the planted acreage continues to grow, the need to extend the marketing season intensifies.

Unfortunately, however, high sensitivity to a number of storage disorders makes long-term storage a serious challenge. Important among these are the chilling injuries soggy breakdown and soft scald (Watkins and Rosenberger, 2000; Watkins et al., 2004, 2005). Delayed cooling or prestorage conditioning of 'Honeycrisp' appears to be effective in controlling soft scald and soggy breakdown (Watkins and Rosenberger, 2000; Watkins and Nock, 2003; DeLong et al., 2004; Watkins et al., 2004, 2005). Successful prestorage conditioning temperatures range from 50-60 °F and 4-7 days in duration (Beaudry et al., 2010).

It has recently been realized that Honeycrisp apples are also sensitive to injury while being stored under controlled atmospheres (Beaudry and Contreras, 2009). This CA-related injury is, in some cases, very similar in appearance to soggy breakdown. It is characterized by brown lesions/patches in the fruit cortex, often with irregular edges and sometimes with the inclusion of lens-shaped openings in the brown lesions (Fig. 1). Unlike soggy breakdown, CA injury does not seem to have a strong scent of fermentation associated with the visible symptoms.

Honeycrisp is not alone in its sensitivity to CA injury. Many fruit cultivars develop physiological disorders in response to low O_2, elevated CO_2 or a combination of both (Pierson et al., 1971). Injury can be manifested as large or small brown lesions, the largest of which are frequently surrounded by a narrow band of healthy tissue at the periphery of the fruit skin, and resemble soggy breakdown (Pierson et al., 1971). CO_2 can cause an injury described as 'brown heart', which is exacerbated by low O_2 (Plagge, 1929). Affected fruit are described as possessing small lesions of brown flesh distributed randomly between the skin and the core (Snowdon, 1990). Initially, the injured tissue is firm and moist, but after prolonged storage they become spongy and dry developing cavities, or lens-shaped voids (Plagge 1929; Snowdon, 1990).

Recently, we reported that the controlled atmosphere injury, like chilling injury, is suppressed by prestorage conditioning treatments (Contreras et al., 2014). We also found that a prestorage treatment with ~1000 ppm diphenylamine (DPA) would essentially eliminate CA-related injury. The prestorage conditioning treatments evaluated were 5 days at either 50 or 68 °F. The higher temperature appeared to provide more protection than the lower temperature. This was somewhat unfortunate in that the lower temperature provides good control of chilling injury and it would be convenient if the lower temperature conditioning treatment could serve the purpose of suppressing chilling injury as well as CA injury.

In order to explore the relationship between the temperature of the conditioning period, its duration and its effectiveness at suppressing CO_2 injury, we devised an experiment that exposed Honeycrisp fruit to several temperature/duration combinations. We proposed that a shorter duration preconditioning period at higher temperatures (68 or 77 °F) could be just as effective as a longer treatment at lower temperatures (e.g., 50 or 60 °F). An additional advantage of a shorter treatment period would be more efficient handling of the fruit prior to storage; if we could develop a 3-day protocol, for instance, . Our concern, however, was that the more 'intense' conditioning treatments might negatively affect quality, so we performed sensory analysis using a trained panel to evaluate the impact of the conditioning treatments on quality and measured the volatile profile of treated fruit to detect "off flavors".

For this project, our working hypothesis was that there exists an optimal preconditioning time-temperature combination for the suppression of CA injuries. However, this result must be interpreted in view of enhancement of any undesirable side-effects of the treatment combinations.

We conducted an experiment to:
1) Identify the most effective and most rapid pre-storage conditioning regimen for CA storage to minimize CA injury
2) Determine the impact of these conditioning regimens on undesirable disorders (e.g., bitter pit and decay)
3) Determine the impact of conditioning treatments on sensory quality.

Figure 1. Internal controlled atmosphere injury from low O_2 and elevated CO_2. Injury can be in small patches or large sections, depending on severity (left). The disorder can lead to the formation of more typical CO_2 injury (right) with time.

In 2013, we secured fruit from 6 orchards from across the state of Michigan. Since the intent was to try to determine the optimal prestorage conditioning treatment, a range of treatment temperatures and durations was created. Fruit were subjected to 0, 1, 3, 5, and 7 days holding at 3, 10, 15, 20, and 25 °C (38, 50, 59, 68, 77 °F, respectively), then held under CA conditions (3% O_2 and 3% CO_2 at 3°C) expected to induce CA injury. After 4 months, the fruit were assessed for the incidence and severity of CA injury, bitter pit, decay, firmness, soluble solids, aroma volatiles and titratable acidity. In addition, we determined the impact of the treatments on the sensory perception of 'ripeness' as determined by a trained panel.

Conditioning temperature and duration did not affect fruit firmness following 4 months storage either the day after removal or after a 7-day simulated retail period at 68 °F, but conditioning at temperatures 10 °C and above reduced the incidence of decay (Figure 2). Importantly, bitter pit was mild to moderate, depending on the grower, but unaffected by preconditioning (data not shown).

Conditioning reduced the incidence of CA injury at all temperatures. The effectiveness of the treatment was improved by increasing the temperature and the duration of the treatment. At 38 °F, 7 days of conditioning reduced sensitivity to CA injury marginally.   Conditioning at 50 °F was slightly better, but not as effective as was hoped. At least 3 days at 68 to 77 °F were required to successfully suppress CA injury (Figure 3). What this means is that a shorter, 3-day prestorage holding period at a minimum of 20 °C can be used by apple storage operators to protect Honeycrisp apple from CA injury.   Storage operators can, therefore, use their space more efficiently than previously thought, with a shorter turn-around time than the 5 days previously thought necessary for conditioning. In addition, storage operators should be able to apply the prestorage conditioning treatments to control CA injury without fear of inducing unwanted, deleterious disorders like bitter pit and decay.

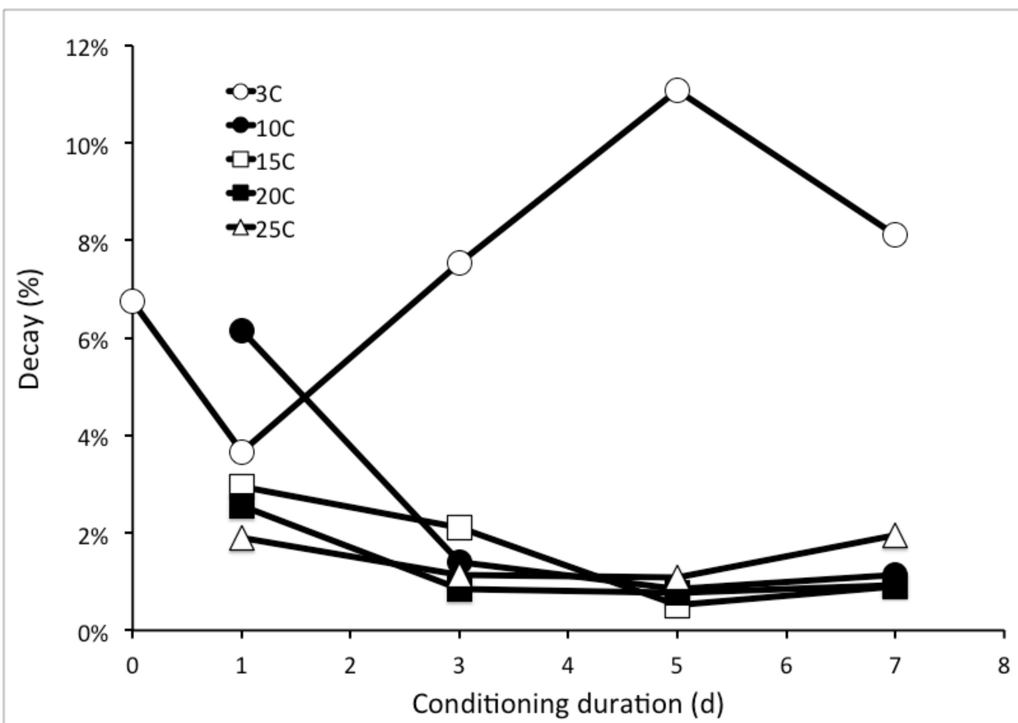


Figure 2. Increasing the duration and the temperature of the prestorage conditioning treatment reduced decay. Decay was highest for the fruit 'conditioned' at 3 °C.

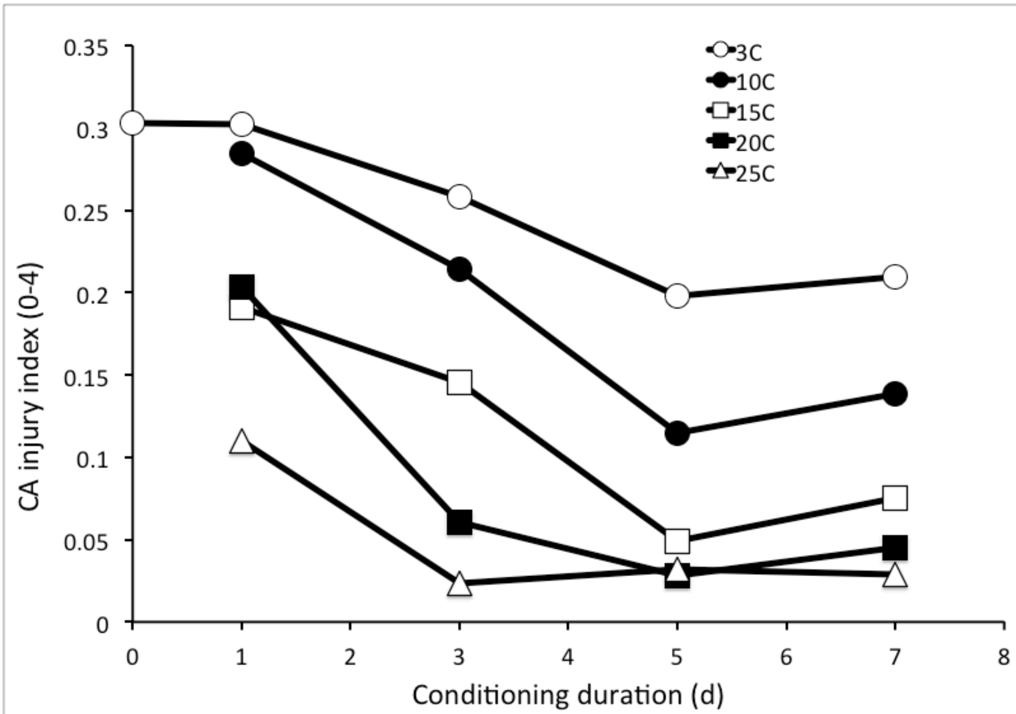


Figure 3. Increased duration of the conditioning period and increased conditioning temperature both contribute to reducing susceptibility of the fruit to CA storage injury.

In an earlier study in 2012, we used a consumer sensory panel to determine if they perceived a decline in quality over time and could discern differences in quality due to conditioning treatments (5 days at 50°F) applied. Fruit were evaluated after 1, 3, and 6 months storage in CA (3% CO_2 and 3% O_2) or in air. A total of 78 panelists evaluated fruit on each date and a trained panel evaluated specific attributes of flavor and condition. The consumer panel could not differentiate between the various treatments or the storage durations, suggesting that the uninformed consumer is not able to readily perceive any differences in fruit ripeness (data not shown). We considered the idea that the consumer panel may have been unbiased since they were informed that the tasting was for Honeycrisp fruit and the favored opinion of that variety may have lead to higher ratings than we might otherwise expect. However, a trained panel was easily able to distinguish differences in ripeness as a function of storage duration. Even the trained panel, however, was not able to clearly distinguish between conditioning treatments.

In the 2013 study, the trained sensory panel again had difficulty distinguishing between conditioning treatments. In this case, they were presented with fruit from four different conditioning treatments differing in 'intensity' with regard to temperature and duration: 0 days conditioning; 5 days at 50 °F, 5 days at 68°F, and 7 days at 77 °F. The panel was asked to judge ripeness, greasiness, tartness, strength of aroma and firmness. The sensory panel could not detect an effect of conditioning treatment on any one of these characteristics, but we did find that conditioning treatment affected a ripeness index, which we calculated as the sum of sensory scores for aroma and greasiness divided by the tartness score. However, the effect was very slight and statistical tests could not demonstrate which treatment differed from the others. Further, we found that prestorage conditioning duration and temperature did not affect titratable acidity (data not shown) and so would be unlikely to affect the perception of tartness, which is consistent with our sensory data. Increasing the intensity of the conditioning treatment increased the synthesis of fermentation volatiles such as ethanol and ethyl esters in Honeycrisp fruit (Fig. 5). However, other aroma compounds were not appreciably affected. The sensory data suggest that the more intense preconditioning treatments do have the potential to compromise perceived quality, albeit only slightly, so that the conditioning temperature and ists duration should be kept at their respective minimums. In this case, the conditioning temperature should probably remain near 20 °C and be applied for no more than 3 to 5 days.

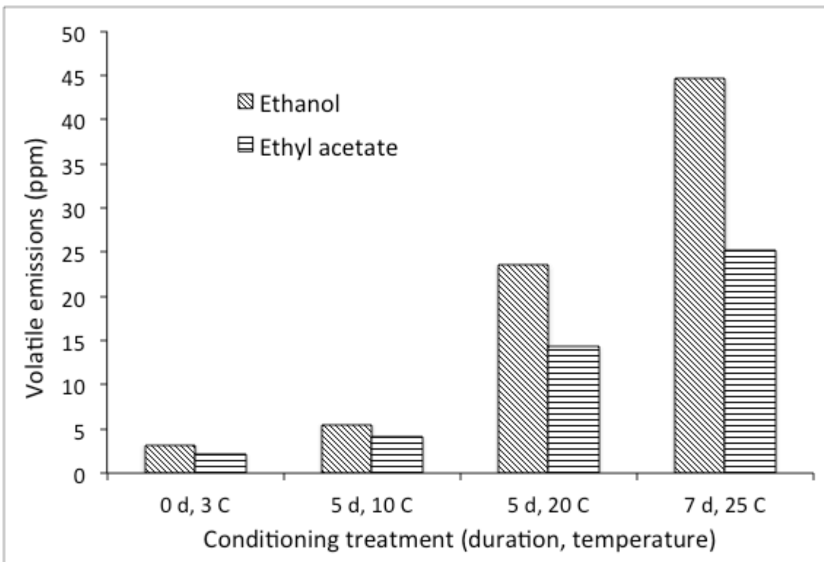


Figure 5. Increasing the intensity of the prestorage conditioning treatment by increasing temperature and the duration of the treatment enhanced the production of volatiles related to fermentation, which are associated with over-ripeness.

Summary

The findings demonstrate to our apple storage industry that Honeycrisp fruit can be stored safely in CA if the fruit are preconditioned properly, thus extending the marketing season and protecting the value of the harvested crop beyond its normal marketing period.
the data from 2013 suggest that apple storage operators may be able to use a shorter, 3-day prestorage holding period (at a minimum of 20 °C) to protect Honeycrisp apple from CA injury without risk of increased incidence of other storage disorders and with minimal impact on fruit flavor.

Our current recommendation for CA storage is to keep CO_2 low in the first month of storage, much in the same way as for Empire, and then allow the CO_2 levels to increase. Our recommended storage temperature remains 38°F for the moment, but with conditioning, somewhat lower temperatures may be successful as well. We recommend some form of protection from CA injury and we have previously had very good success for three successive years (Contreras et al., 2014) with 5 days at 68 °F. However, the more recent data shared here suggests a shorter conditioning period may be similarly effective, but additional testing is required at this point since this represents only a single year's data. It is also worth noting that DPA is very effective at suppressing CA injury in Honeycrisp and would certainly be able to substitute for a preconditioning treatment in terms of controlling this disorder. However, since DPA has only a very slight suppressive effect on chilling injury (Watkins et al., 2004), a minimal prestorage conditioning treatment (5 days at 50°F) is still advisable in air or CA storage. Another alternative to CA storage is the use of 1-MCP to suppress ripening. Results so far have been quite favorable, but there may be a slight enhancement of sensitivity to CO_2 injury. For this reason, we strongly recommend monitoring CO_2 levels during room loading and the initial cooling period, venting the room if necessary.

Literature cited

Beaudry, R. and C. Contreras. 2009. A summary of 'Honeycrisp' storage recommendations across North America: What is best for Michigan? Proc. 2009 Great Lakes Fruit, Vegetable and Farm Marketing Expo. http://apples.msu.edu/pdf/HoneycrispStorageRpt09.pdf.

Beaudry, R., J. DeEll, E. Kupferman, J. Mattheis, C. Tong, R. Prange, and C. Watkins. 2010. Region-By-Region Storage Recommendations For Honeycrisp: Responses from apple storage researchers. Proc. 2009 Great Lakes Fruit, Vegetable and Farm Marketing Expo. http://apples.msu.edu/pdf/RegionalRecHoneycrisp.pdf.

Contreras, C., N. Alsmairat, and R. Beaudry. 2014. Prestorage conditioning and diphenylamine improve resistance to controlled-atmosphere-related injury in 'Honeycrisp' apples. HortScience 49:76-81.

DeLong, J.M., R.K. Prange, and P.A. Harrison. 2004. The influence of pre-storage delayed cooling on quality and disorder incidence in 'Honeycrisp' apple fruit. Postharvest Biol. Technol. 33:175-180.

Pierson, C. F., M. J. Ceponis, and L. P. McColloch. 1971. Market diseases of apples, pears and quinces. Agricultural Research service, United States Department of Agriculture. Agriculture Handbook 376.

Plagge, H. 1929. A study of soggy breakdown and some related functional diseases of the apple. Proc. Amer. Soc. Hort. 26:315-318.

Snowdon, A.L. 1990. A color atlas of post-harvest diseases and disorders of fruits and vegetables. Vol. I CRC Press, Boca Raton, FL.

Watkins, C.B., M. Erkan, J.F. Nock, K.A. Iungerman, R.M. Beaudry, and R.E. Moran. 2005. Harvest dates effects on maturity, quality, and storage disorders of 'Honeycrisp' apples. HortScience 40:164-169.

Watkins, C.B. and J.F. Nock. 2003. Postharvest Treatments to Decrease Soggy Breakdown and Soft Scald Disorders Of Honeycrisp Apples. New York Fruit Quarterly, 11:33-35.

Watkins, C.B., J.F. Nock, S.A. Weis, S. Jayanty, and R.M. Beaudry. 2004. Storage temperature, diphenylamine, and pre-storage delay effects on soft scald, soggy breakdown and bitter pit of 'Honeycrisp' apples. Postharvest Biol. Technol. 32:213-221.

Watkins, C.B. and D.A. Rosenberger. 2000. Honeycrisp - some preliminary observations. 2000. Cornell Fruit Handling and Storage Newsletter [http://www.hort.cornell.edu/watkins/CAnews00.pdf].

DECCO

Decco NoScald DPA Aerosol*
"The Dry Fog"

Clean, Effective and Environmentally Friendly Method of Apple Scald Control

DPA (Diphenylamine) is the most effective apple scald inhibitor available. It is commonly applied as a postharvest drench treatment. However this aqueous application method generates huge amounts of spent emulsion that has to be disposed off according to current laws and regulations. In addition the reuse and recirculation of the emulsion leads to accumulation of disease causing pathogens.

To overcome the above disadvantages and speed up the treatment process, Decco took the approach for developing an aerosol application process with the highest DPA concentration possible. After conducting several research trials we decided for pure DPA as the end use product. Using pure molten DPA as an aerosol eliminated the use of solvents and surfactants and consequently reduced the environmental impact. In addition it cut down the application time by 90% compared to available fogging method. We favored the use fuel powered fumigation gun rather than an electrical, for:

- Aerosol resulting in smaller particle sizes.
- Application of the DPA in partially carbon dioxide atmosphere to avoid its oxidation.
- Consideration that carbon dioxide is a component of CA condition and its concentration is managed during the storage period.
- Flexibility of moving and operating the lightweight fogging machine anywhere.
- Independence of high voltage electrical power source.

<u>Additional Advantages of Decco DPA Aerosol Process:</u>

- Very environmentally friendly. All DPA is utilized. No other ingredients.
- Produces no condensates. No need for covering of top bins.
- Rapid application. 90% faster than other available process. Cuts heat stress on fruit.
- Simultaneous application of pure fungicides. Cuts heat stress on fruit.
- Safe handling and storage. No bulky packaging.
- Less decay and staining of fruit due to non-aqueous application.
- No need of container rinse and disposal.
- No need of extra bin spacing and rearrangement.

*) Patent pending

DECCO US POST-HARVEST
UNITED PHOSPHORUS LIMITED
1713 SOUTH CALIFORNIA AVENUE • MONROVIA, CALIFORNIA • 91016
PHONE: 626-359-[illegible] FAX: 626-355-7248

GROUP 12 FUNGICIDE

PULL HERE TO OPEN ►

Scholar® EZ

syngenta

Fungicide

Scholar EZ is concentrated fludioxonil intended for post-harvest thermal fogging on pome fruit.

Active Ingredient:	
Fludioxonil*	98.0%
Other Ingredients:	2.0%
Total:	100.0%

*CAS No. 131341-86-1

Scholar EZ is a 98% powder.

KEEP OUT OF REACH OF CHILDREN.

CAUTION

See additional precautionary statements and directions for use inside booklet.

EPA Reg. No. 100-1505

EPA Est. 67545-AZ-1

SCP 1505A-L1 0314

4036690

Do not formulate this product in to other end-use products.

1.1 lb (500 grams)

(17.6 oz)

Net Weight

DECCO

CUSTOMER SERVICE

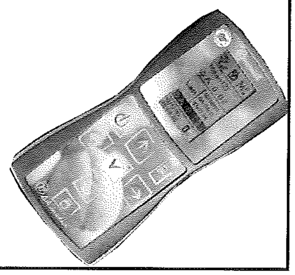
Phone: 1-800-233-3228
Fax: 1-888-870-5358
Email: DECCOUS@uniphos.com

Hours: 7:00 am – 4:00 pm (PST)
Monday – Friday

Experiences with the DA Meter

Chris Watkins

Cornell University, Ithaca, NY



The collective research of

Franny Doerflinger
Yosef Al-Shoffe
Jackie Nock
Shao Xingfeng
Kazem Arzani

With funding from

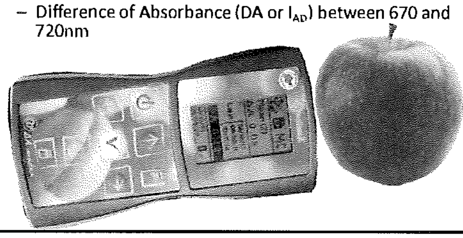
- **AgroFresh**
- **NY Apple Research and Development Program**
- **USDA-NIFA**

And assistance from AgroFresh team responsible for Harvista trials

- Nate Reed
- Fernando Edagi
- Ken Silsby
- Keith Culver

I_{AD} measurements with the DA meter

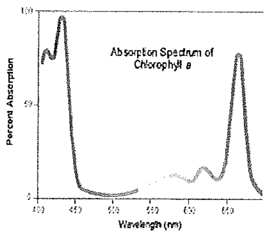
- DA meter
  - Hand held non-destructive measurement
  - Developed from vis/NIR spectroscopy
  - Difference of Absorbance (DA or I_{AD}) between 670 and 720nm



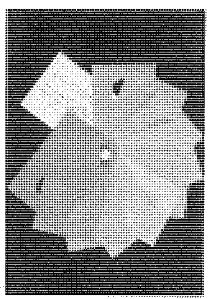
Absorbance measurement principles

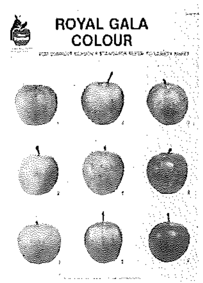
I_{AD} measurement:

- Chlorophyll *a* peaks at ~660 nm
- I_{AD} measures Chlorophyll *a* in the peel
  I_{AD} = Abs (670 nm) – Abs (720 nm)



Essentially an electronic color chart



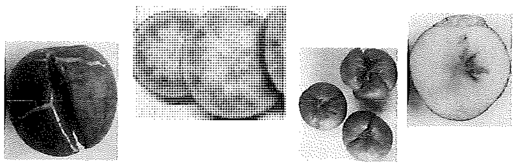


But DA meter is not limited by red coloration of fruit

DA meter provides readings in the range of 0 to 3.0 for apple fruit

Why are we interested?

Harvest date is critical to quality of fruit in the market place, and often associated with storage disorder issues



An additional tool to ethylene, SI, SSC, TA?
Non-destructive

Recent published research on the DA meter for apple fruit - examples

- I_{AD} values at harvest and after storage correlated with firmness, SSC and TA of 'Red Delicious', 'Granny Smith' and 'Pink Lady' – potential to sort fruit at harvest and after storage for different marketing classes (Nyasordzi et al., 2013).
- I_{AD} values do not relate to storage quality (other than chlorophyll (background greeness)) in fruit stored in CA or treated with 1-MCP (Toivonen and Hampson, 2014)
- I_{AD} values of 0.59 to 0.36 proposed as 'start' and 'finish' dates for long term air stored 'Honeycrisp' apples (DeLong et al., 2014).

Objectives

To evaluate the DA meter by determining the relationships between I_{AD} values and:

- Other harvest indices such as ethylene and starch indices
- Storability of fruit of different cultivars, especially incidence of physiological disorders
- Effects of preharvest factors such as Harvista and other plant growth regulators (PGRs)

Some of our studies

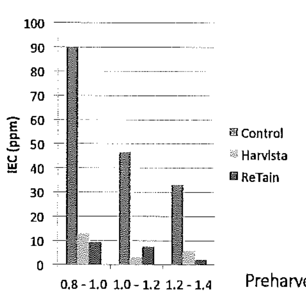
1. 'Delicious' apples untreated or treated with Harvista (preharvest 1-MCP) or ReTain (AVG) to investigate relationships between I_{AD} values, harvest indices and superficial scald (Arzani et al.)
2. 'Honeycrisp' apples untreated or treated with Harvista to investigate relationships between I_{AD} values and soft scald (Al-Shoffe et al.)
3. Relationships between I_{AD} values and harvest indices in fruit of 9 apple cultivars (Shao et al.)
4. Relationships between I_{AD} values and harvest indices in fruit from different growing regions from commercial Harvista trials (Doerflinger et al.)

1. Delicious and superficial scald

- Replicate 'Delicious' trees untreated or sprayed with Harvista or ReTain (gift from Valent Biosciences)
- Fruit harvested and divided into categories based on DA meter readings
- Internal ethylene concentrations (IECs) measured and fruit stored for scald development

Only at harvest results today

I_{AD} values and internal ethylene concentrations (ppm)



- Relationships between and I_{AD} values good for untreated fruit

  – lower I_{AD} values = riper fruit and higher IEC.

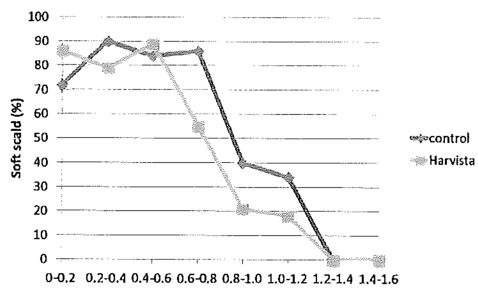
- Harvista and ReTain trts result in loss of relationship within an given I_{AD} value.

Preharvest factors such as PGR may interfere with interpretation of DA meter readings

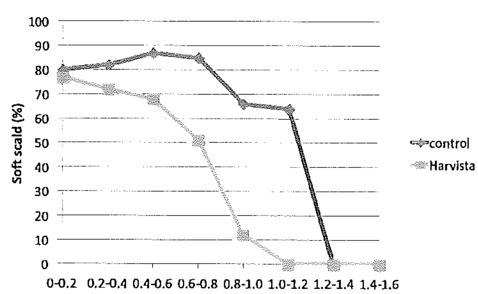
2. 'Honeycrisp' and soft scald incidence

- Replicate 'Honeycrisp' trees untreated or sprayed with Harvista
- Fruit harvested at three 1-week intervals and divided into categories based on DA meter readings
- Internal ethylene concentrations (IECs) measured and fruit stored at 33°F for soft scald development

Soft scald (%) in Honeycrisp apples at different I_{AD} value categories: Harvest 1



Soft scald (%) in Honeycrisp apples at different I_{AD} value categories: Harvest 2

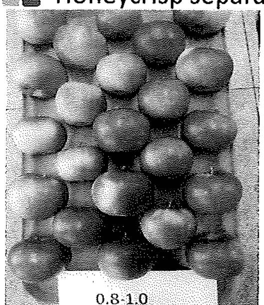


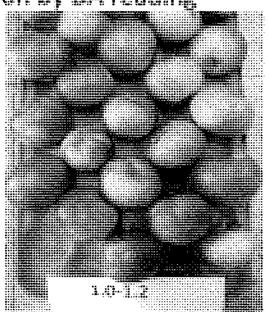
Summary

- Soft scald incidence is higher in less ripe fruit (lower I_{AD} values).
- Harvista can decrease soft scald development.
- However, relationship between disorder development and I_{AD} values can be dissociated by
  - Harvest date
  - a PGR such as Harvista.

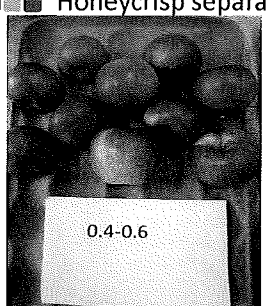
Note - Commercial acceptability of fruit may over-ride decisions made on basis of I_{AD} values.

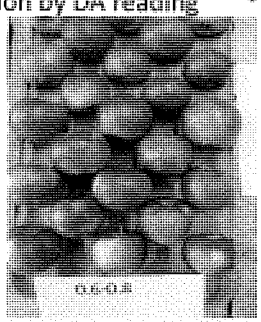
Honeycrisp separation by DA reading





Honeycrisp separation by DA reading





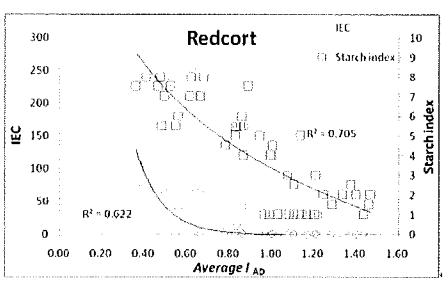
3. Relationships between IAD values and harvest indices for 9 cultivars

- Harvest indices plus I_{AD} values assessed at weekly intervals for several weeks

Relationships between I_{AD} values and chlorophyll a

Cultivar	R^2
NY-1	0.797
NY-2	0.756
Cortland	0.818
Fuji	0.732
Honeycrisp	0.817
Jonagold	0.481
Mutsu	0.678
McIntosh	0.671
RedCort	0.633

Example of relationship between IEC and SI with I_{AD} values



But even more variable for other cultivars. Unknown if consistent across orchards

Summary:

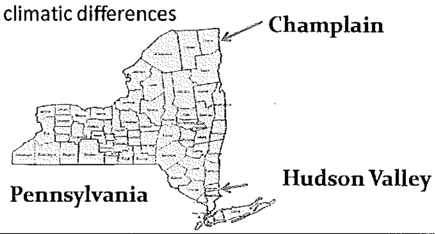
- Generally good correlations between I_{AD} values and chlorophyll concentrations, but exceptions exist.
- Depending on cultivar (e.g. 'RedCort'), relationships between I_{AD} values and IEC and starch indices are good. Suggests that in some cases might be useful non-destructive measure if relationships apply across orchards and growing regions.

4. Relationships between IAD values and harvest indices in fruit from different growing regions from commercial Harvista trials

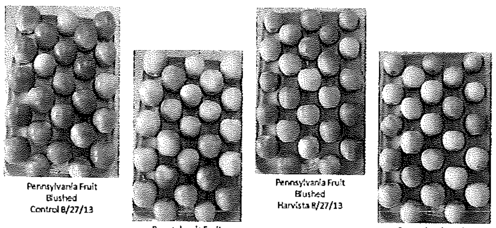
- Application of Harvista by AgroFresh team one week prior to first harvest
- Two harvests of Control and treated fruit
- Data used to evaluate fruit responses to Harvista and to assess relationships with other harvest indices

Material and Methods

- Three cultivars: 'Gala', 'Honeycrisp' and 'McIntosh'
- Four growing regions: Pennsylvania, NYS: Hudson Valley, western NY & Champlain region
- Distinct climatic differences



'Gala: Two regions



Pennsylvania Fruit
Blushed
Control 8/27/13

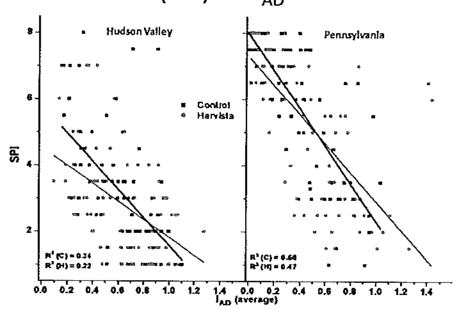
Pennsylvania Fruit
Unblushed
Control 8/27/13

Pennsylvania Fruit
Blushed
Harvista 8/27/13

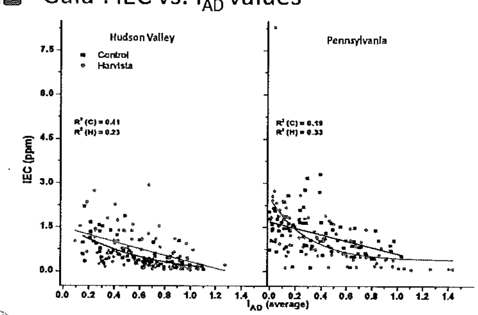
Pennsylvania Fruit
Unblushed
Harvista 8/27/13

'Gala' treated & untreated with Harvista from Pennsylvania and Hudson Valley

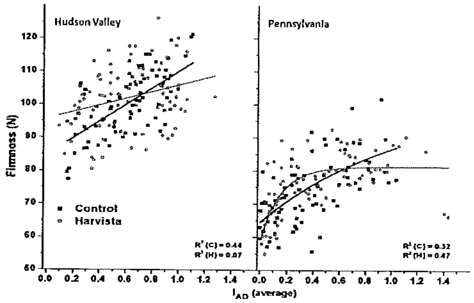
Gala: Starch (SPI) vs. I_{AD} values



'Gala': IEC vs. I_{AD} values



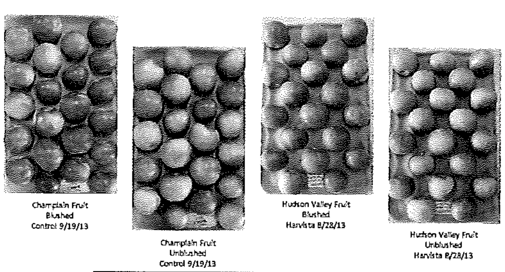
'Gala': Firmness vs. I_{AD} values



Summary: 'Gala'

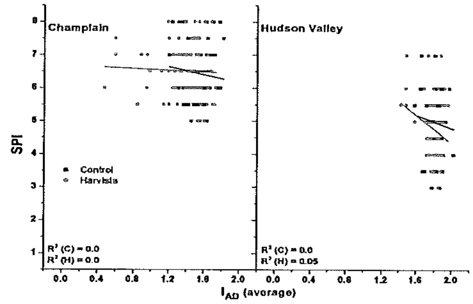
- Starch indices higher at any given I_{AD} value for PA than NY, and stronger relationships for PA than NY and for control than Harvista treated fruit.
- Generally weak relationships between IEC and I_{AD} values.
- Firmness of fruit higher in NY than in PA, but overall weak relationships.

'McIntosh': Two regions

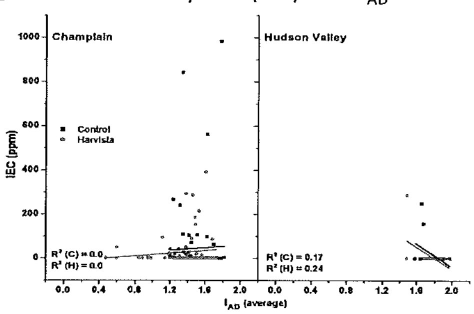


'McIntosh' treated & untreated with Harvista from Champlain and Hudson Valley

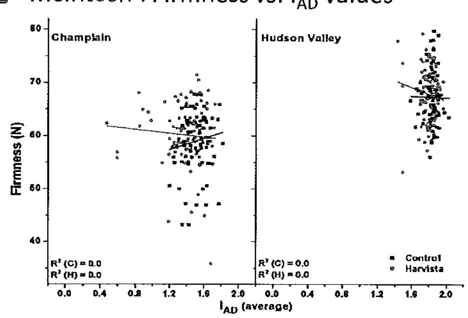
'McIntosh': Starch (SPI) vs. I_{AD} values



'McIntosh': Ethylene (IEC) over I_{AD} values



'McIntosh': Firmness vs. I_{AD} values

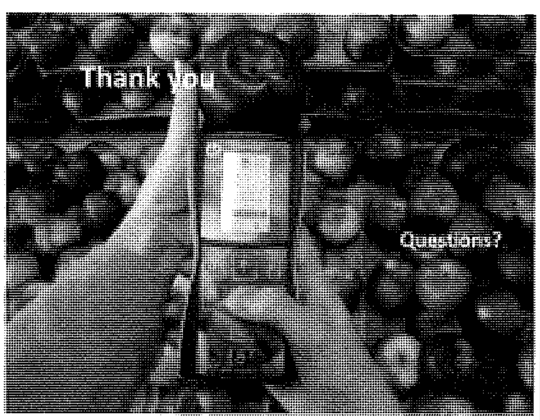


Summary: 'McIntosh'

- No relationships between I_{AD} values and other factors.
- Indicates usefulness of DA meter varies by cultivar.

Conclusions

- Correlations of I_{AD} values with other harvest indices are present, but variable, and depend on cultivar.
- Relationship between I_{AD} values at harvest and disorders may be affected by preharvest factors such as PGRs.
- Research is ongoing to investigate its usefulness for cultivars within and across different growing regions.
- Overall unlikely to replace standard harvest indices, but rather supplement, although future potential for precision harvest if reliable in the field.
- Must relate to existing market expectations.



Pace International

Latest advancements in thermofogging and drenching solutions

September 6, 2014

MSU CA Clinic

David Felicetti

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

Pace International

The Leading Postharvest Specialist

Innovative Technologies

High Quality Products

Efficient Application Systems

Professional Services & Support

Global Experience & Research

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

Pace ecoFOG®

With US patent pending

PROCLEAN™ TECHNOLOGY

- Electro-Thermofogger
  - No Combustion Gas
- Manifold (in storage room)
  - Even Residue distribution
  - Air-flow management
- Room Pressure monitoring and control
  - Controlled exhaust
- PROCLEAN™ technology maximizes application while preventing release of fogging substances into the atmosphere.

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

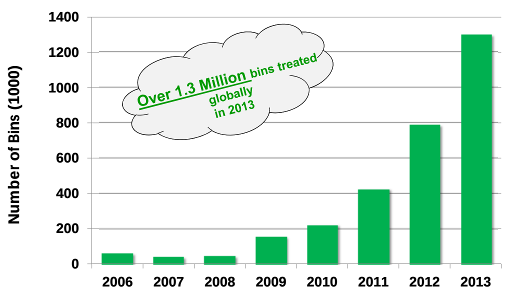
Pace ecoFOG®

- Highly effective method of applying postharvest products:
  - Diphenylamine
  - Ethoxyquin
  - Pyrimethanil
  - Fludioxonil
  - Thiabendazole

With US patent pending

PROCLEAN™ TECHNOLOGY

Global Volume of Bins Treated
2006-2013



A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

©2014 Pace International LLC – All Rights Reserved

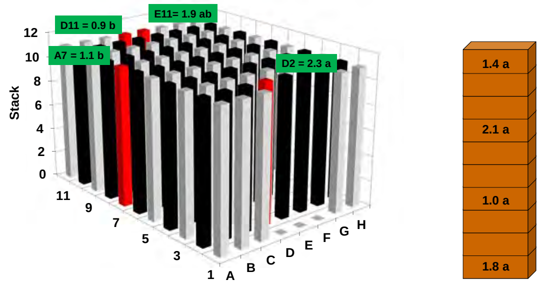
THERMOFOGGING FUNGICIDES IN POME FRUIT

eFOG™-80
(8% fludioxonil)

Pace International

eFOG™-80

Golden Delicious (935 bins)



FDL residues 2 month Cold storage after eFOG™-80 application

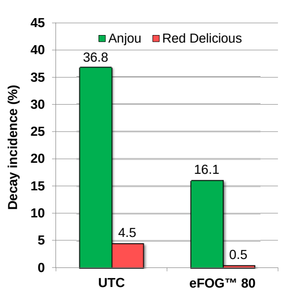
eFOG™-80 vs. Fludioxonil drench

Packer (Variety)	Months in CA	Treatment	Percent in the total decay				Total decay (%)
			Gray mold	Blue mold	Mucor	Others	
A (Fuji)	1	FDL-drench	16.4	26.2	3.3	44.3	0.19 a
		eFOG™- 80	24.3	27.0	0	32.4	0.12 b
B (Red)	10	FDL-drench	60.8	1.0	36.1	2.2	1.80 a
		eFOG™- 80	79.7	0	14.2	5.6	1.90 a

- Apples (Fuji and Red Delicious) were fogged with eFOG™ 80 (60g/ton) at Pace International facility and delivered to commercial CA storages. Drench treatments were performed at the packer's commercial drenchers using the fruit from the same grower lots as the fogging treatments.
- In Packer A, eFOG™ 80 showed statistically better efficacy than FDL-drench, while no difference was observed in Packer B.
- In both packers, the percent of Mucor rot in the total decayed fruit was lower in eFOG ™ 80 than that of FDL-drench.

eFOG™-80

Efficacy



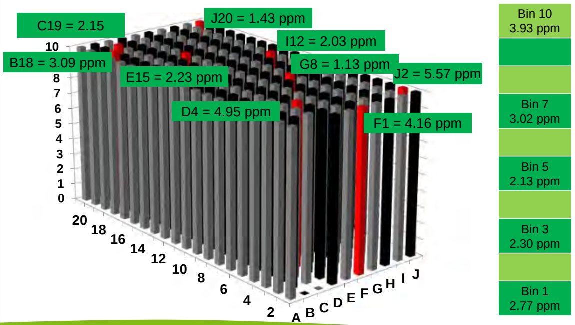
- Organic Anjou pears and Red Delicious apples were fogged with eFOG™-80 (60g/ton).
- After the treatments, pear and apple fruit were stored at ambient temperature (50-60°F) for 2 and 6 months, respectively.
- Decay incidences were evaluated based on natural infections.
- eFOG™-80 significantly reduced the decay incidences by 20.7% in Anjou pears and 4% in Red Delicious apples.
- eFOG™-80 would be an ultimate alternation partner to ecoFOG™-160 (pyrimethanil) for the fungicide resistance management.

THERMOFOGGING FUNGICIDES IN POME FRUIT

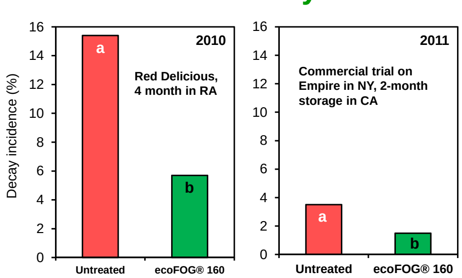
ecoFOG®-160
(16% pyrimethanil)

Pace International

ecoFOG®-160
Gala Apples (1980 bins)



ecoFOG®-160
Efficacy



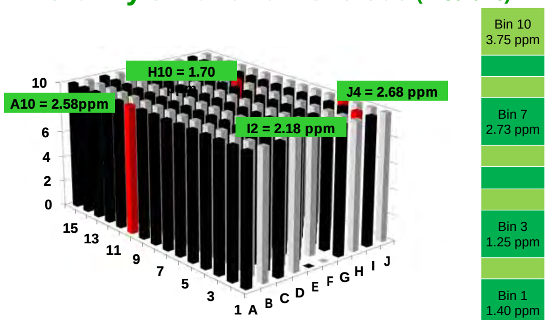
Significant decay reduction within 2 months of storage

THERMOFOGGING SCALD CONTROL IN APPLES

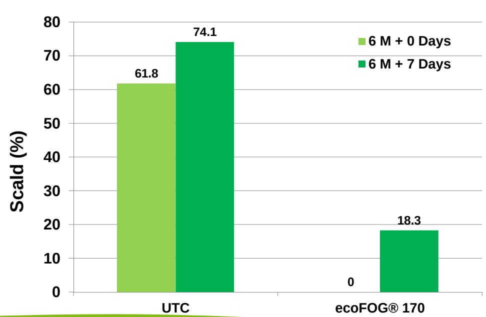
ecoFOG® -170 DPA
(17% diphenylamine)

Pace International

ecoFOG®-170
Granny Smith and Delicious (1480 bins)



ecoFOG®-170
Scald on Granny Smith Apples



The latest in FDL Fungicide Technology

Shield-Brite® FDL 230SC

- Easy to use liquid "Suspended Concentrate" formula.
- Active Ingredient: 20.4% Fludioxonil.
- Convenient Packaging:
  100 fl. oz. per jug, 2 jugs per box
  1 jug added to 1,000 gallons of drench solution = 180 ppm Fludioxonil
- Expected residue range when applied by drenching should be between 0.2 ppm – 0.8 ppm for pome fruit.
- Compatible with other postharvest treatment including chlorine, coatings, DPA and Semperfresh®*
- Optimal dispersion and suspension stability
- For latest MRL list, please visit: www.mrldatabase.com

*SEMPERFRESH is a registered trademark of Agricoat Industries Ltd.

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

The latest in FDL Fungicide Technology

Shield-Brite® FDL 230SC

- Fludionoxil: effective control of Blue mold, Gray mold, Speck rot, Sphaeropsis rot, Phacidiopycnis rot, and many other postharvest diseases.
- Strong preventative & curative effect (kick-back activity).
- Shield-Brite® FDL 230SC acts on a different mode of action than TBZ and pyrimethanil, allowing control of TBZ-R and PYR-R pathogens.
- Stable Fludioxonil fruit residues during storage. Shild-Brite® FDL 230SC remains to protect fruit during the packing process.
- Fludioxonil is classified as a reduced risk fungicide by EPA and proved no phytotoxicity in commercial applications on apples and pears.

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

Thank You

A Subsidiary of Valent BioSciences Corporation
A Sumitomo Chemical Company

Dynamic CA Storage

Chris Watkins
Cornell University
Ithaca, NY

'Dynamic CA' a paradigm shift?

- The atmosphere composition is not static, i.e. set at specific, constant gas levels,

instead

- with DCA the plant product physiology controls the atmosphere composition,
- i.e. dynamic and affected by fruit metabolism

Zanella, 2014

Principles of 'Dynamic CA' storage

- CA levels respond to <u>actual</u> fruit needs
- Flexible CA values <u>during</u> storage

⇒ Optimized CA conditions with consequent benefits on fruit quality

<u>Fitting CA conditions to the commodity:</u>

- Cultivar
- Maturity
- Seasonal quality variation
- Location influence
- Ripening during storage

Zanella, 2014

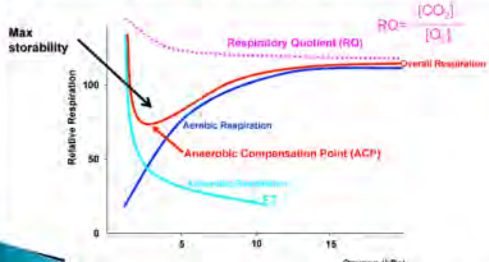
Reasons to focus on the lower O_2 limit

- Decreasing the O_2 limit as low as possible in CA:
  - Slows down the aerobic respiratory metabolism and inhibits oxidative processes
  - Control of superficial scald

Identification of LOL

The respiratory quotient **RQ** is the ratio of CO_2 respired over O_2 consumed

$$RQ = \frac{[CO_2]}{[O_2]}$$



Zanella, 2014

Measuring the Low oxygen limit (LOL)

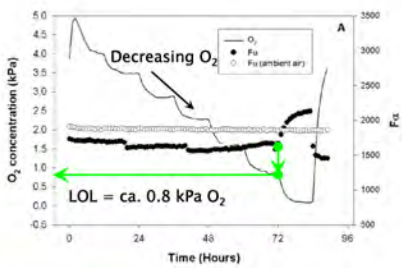
At least three methods available

1. Ethanol accumulation in the fruit
2. The respiratory quotient (carbon dioxide/oxygen)
3. Chlorophyll fluorescence

DCA - CF (HarvestWatch)

IsoCell – DeLong and Wright, NS

Using HarvestWatch to determine LOL in apple



HarvestWatch containers in storage bins

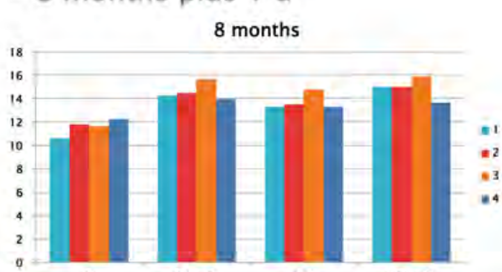
Our first experiments

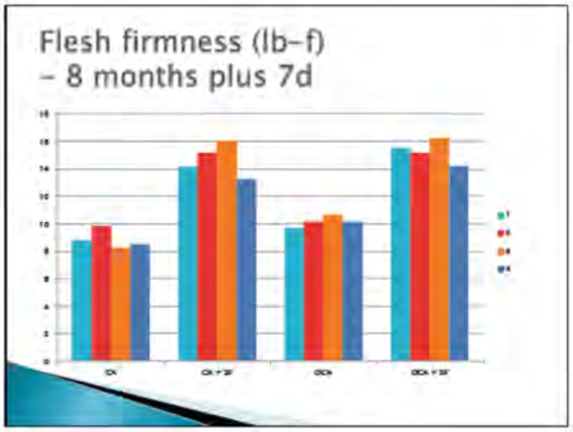
- **McIntosh (0.9–1.1% oxygen)**
- **Delicious (0.4–0.6% oxygen)**
- Empire (0.4–0.6% oxygen)

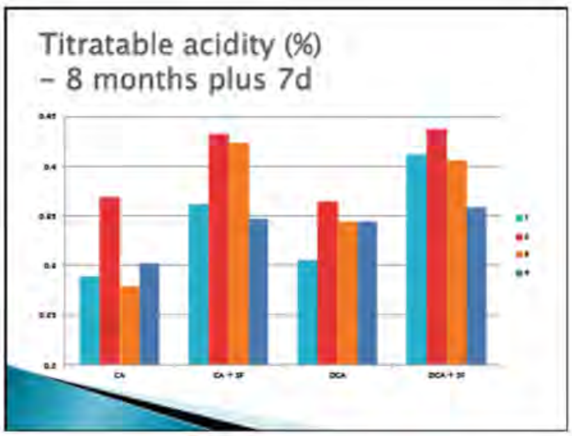
McIntosh (Champlain) – assessment at harvest

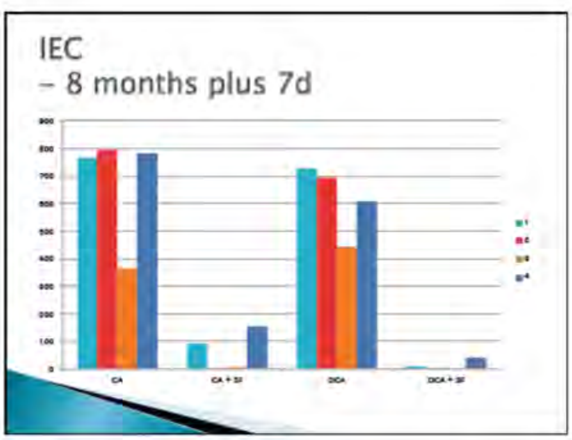
Orchard	IEC (ppm)	Firmness (lb)	SSC (%)	Starch index	I_{AD} mean
1	0.31	14.9	13.0	5.1	1.58
2	1.49	14.6	13.1	5.7	1.62
3	0.12	16.1	13.5	3.9	1.52
4	3.07	14.2	11.9	4.9	1.53

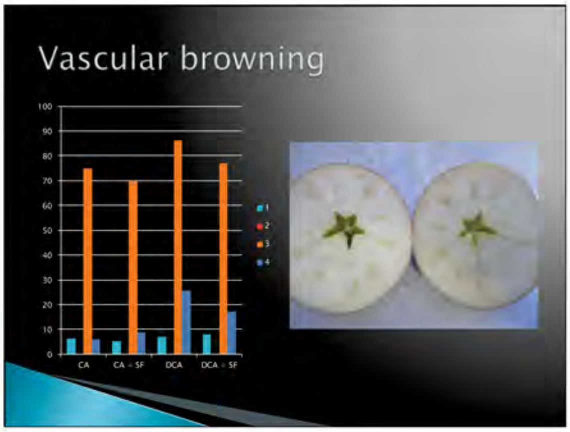
Flesh firmness (lb-f) – 8 months plus 1 d



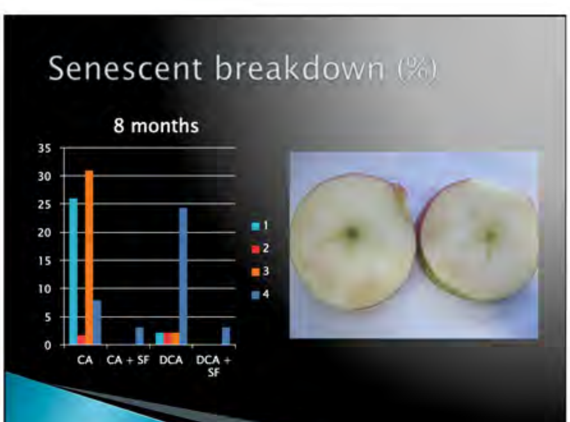

Flesh firmness (lb-f)
– 8 months plus 7d


Titratable acidity (%)
– 8 months plus 7d


IEC
– 8 months plus 7d


Vascular browning
100
90
80
70
60
50
40
30
20
10
0
CA
CA + SF
DCA
DCA + SF
1
2
3
4

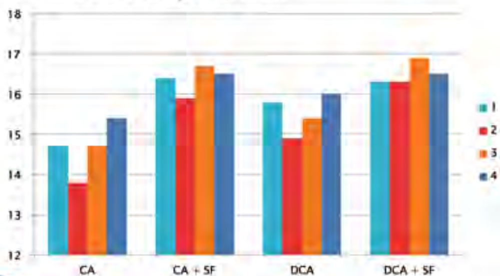

CO_2 injury
8
7
6
5
4
3
2
1
0
CA
CA + SF
DCA
DCA + SF
1
2
3
4


Senescent breakdown (%)
8 months
35
30
25
20
15
10
5
0
CA
CA + SF
DCA
DCA + SF
1
2
3
4

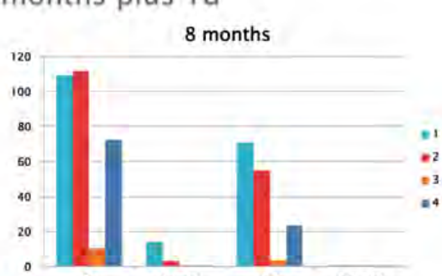
Delicious
– assessment at harvest

orchard	IEC (ppm)	Firmness (lb)	SSC (%)	Starch index	I_{AD} mean	% water core
1	19.31	16.1	11.9	4.3	1.49	43.3
2	19.30	16.4	11.9	3.8	1.36	50.0
3	0.97	17.4	12.3	4.3	1.19	86.7
4	0.31	16.7	10.1	3.3	1.64	0.0

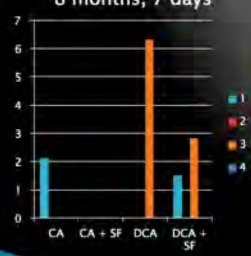
Flesh firmness (lb-f)
– 8 months plus 7d



Delicious IEC (ppm)
– 8 months plus 1d



Water core breakdown (...)



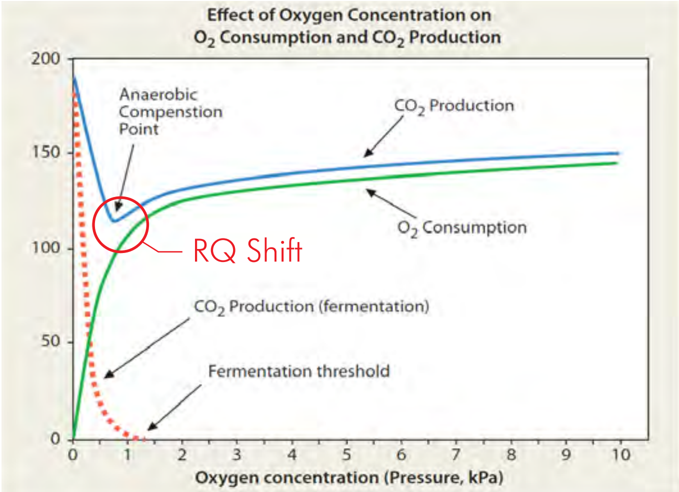
Future prospects

Open mind and just beginning

- Can we get the homogenous fruit required for successful DCA (NY has had bad experiences with low oxygen storage)?
- For scald-susceptible varieties may provide only means of control if DPA is lost to our industries
- Otherwise, difficult to see advantages compared with SmartFresh

SAFEPOD SYSTEM

SafePod & Controller in CA Storage at the SCS Research Lab



FEATURES

- Patented Technology - U.S. Patent No. 8739694, Canadian Patent Pending
- Experiment with ULO/DCA without the risk
- Create an Independent Environment, even within a Larger CA Room
- Test Using Representative Samples from the CA Room
- Integrated Analyzers & Remote 6000 Controller
- Reduces Operating Costs through Energy Savings

Storage Control Systems, Inc. has developed an entirely new way to test your storage process, the SafePod. This patented system creates a chamber comprised of representative samples of fruit inside a larger CA storage, allowing the operator to test for the lowest possible oxygen level of the stored produce without the potential risk of damaging the entire CA store. The units have high-resolution built-in analyzers and an automatic RQ (respiration quotient) measuring system, all of which tie back to our highly popular and remotely-located 6000 controller. We even offer a variant of the system called LabPod, which adds the ability for the unit to regulate its own O_2/CO_2 with or without being inside the larger CA room.

The process is simple. When loading a room, pull a few samples of fruit from each bin as you load, filling the totes inside the SafePod. The SafePod is then placed inside a bin or left separate of the bin stacks inside the CA storage. The built-in, remotely operated SCS Electric Slide Valve on the bottom of the SafePod is opened and the fan is turned on. The fruit inside the SafePod automatically pulls down with the rest of the room. When desired, the SafePod valve can be closed, creating an air-tight and completely independent chamber within the larger CA store, free of any outside influences. This leaves the storage operator the opportunity to experiment on samples of the exact fruit in the larger storage without risking the investment of the entire room. This freedom from risk allows the operator to push the ULO limits to find the best balance for the fruit. ULO levels can be achieved easily, then controlled and indicated by any number of methods, including ethanol sensors, chlorophyll fluorescence, respiration quotient or even gas chromatograph. After an indication of stress on the fruit is noticed, simply raise the O_2 levels by a tenth of a percent or two until the desired results are achieved and the indications of stress disappear.

Once safe levels are dialed in using the SafePod, the entire storage can then be pulled down to match these safe, predetermined ULO levels. Never before has it been so easy, and more importantly relaxing, to run very low oxygen levels. The valve on the SafePod is then opened, marrying the SafePod and larger CA storage atmosphere. The operator can then repeat the entire process later in the storage period to test for additional stresses and possible lower level as the fruit matures.

SafePod

www.SafePodCA.com

STORAGE CONTROL SYSTEMS
100 APPLEWOOD DRIVE • SPARTA MICHIGAN 49345
T 800.487.7994 • P 616.887.7994 • F 616.887.1128
WWW.STORAGECONTROL.COM • INFO@STORAGECONTROL.COM

Starch Iodine Testing

For Timing Harvista™ Applications

Ken Silsby, Eastern Technical Manager

2014 Harvista Program

Starch Iodine Index

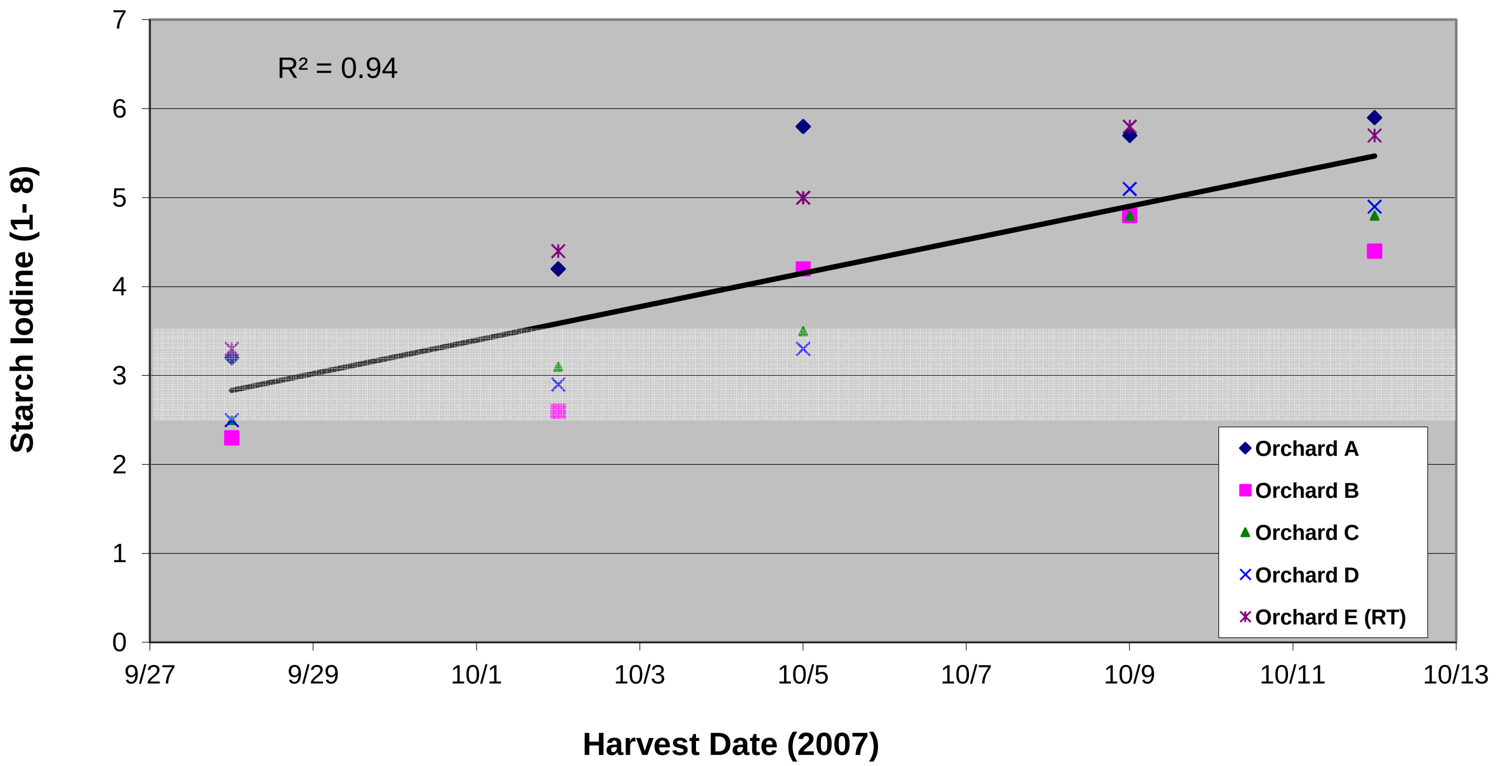
Best practical index for timing applications

- Recommended ranges available for common varieties
- Movement is steady
  - Generally, one unit per week for most varieties
- Change generally begins before recommended timing
  - More difficult for varieties with low starch maturity ranges
    - Reduced lead time before application timing

Starch Test Limitations

- Variation among similar blocks often two or more units
  - Not necessarily related to actual maturity
  - Consider use of regional averages
  - Normal calendar harvest dates are also helpful
    - Adjusted for earliness of season
- Consistent sampling and testing protocols required
  - To reduce variability in results
- Use logical, reasoned approach in interpreting data

Starch Iodine Index of Five WNY Empire Orchards in 2007 (mean of 10 apple samples)



Suggested Starch Index at Harvista application = 2.5 – 3.5 (lightly shaded area)
Harvest range generally = 3.5 – 5.0

Suggested Starch-Iodine Index at Maturity

Variety	Suggested Range	Source
McIntosh	3.0 – 5.0	Silsby (estimate)
Cortland	1.5 – 3.5	Silsby (estimate)
Spartan (Aceymac)	2.5 – 3.5	Lau, 1985
Empire	3.5 – 5.0	Silsby, 1993
Jonagold	5.0 – 7.0	Silsby, 1993
Delicious	2.8 – 3.5	Priest & Lougheed, 1981
Idared	2.5 – 5.0	Silsby (estimate)
Law Rome	3.0 – 6.0	Salveit & Hale, 1982
Crispin (Mutsu)	3.5 – 5.5	Silsby (estimate)

See also: SmartFresh^{SM} Apple Use Recommendations (revised annually)

Recommended Harvista Application Timing

Apple Variety	Optimum Mean Starch Index*	Application Timing (before anticipated harvest)
Gala	2.0 – 3.5	3 – 14 days
McIntosh	3.0 – 4.0	3 – 14 days
Honeycrisp	4.0 – 5.0	3 – 14 days
Empire	2.5 – 3.5	3 – 14 days
Jonagold	5.5 – 7.0	3 – 14 days
Red Delicious	1.5 – 2.5	3 – 14 days
Golden Delicious	3.0 – 5.0	3 – 14 days
Idared	2.5 – 4.5	3 – 14 days
Fuji	2.5 – 4.5	3 – 14 days

*Generic Starch-Iodine Index (1 – 8 scale)

•Generally, one unit less than mature range

•Timing may be based upon regional averages

Sampling Procedures

- Sample once per week starting 3 – 4 weeks prior to harvest
  - > 10 apples samples are sufficient
  - > But, larger sample size adds confidence
- Select trees that are representative
  - > Crop load and tree vigor
  - > Avoid ends of rows
  - > Tag selected trees for repeat or follow up sampling
- Sample from different sides of trees
  - > Within easy reach
  - > Not more than 2 apples per tree
- Select apples of representative size with good light exposure
  - > Avoid apples with advanced maturity
  - > Sunburn, cracking, insect damage, others

Sunny vs Shaded Side

•Red side = greater starch (lower index)
•Confirms impact of accumulated starch due to crop load, cultural practices, growing conditions, and others

Shaded vs Exposed Apples

•Apples collected from same tree
•Well exposed apples contain more starch (lower index)

Testing Procedure

- Test within 24 hours
  - > Adapted to field testing
- Cut in half near “equator” of apple
  - > Cut should dissect seed cell cavities
- Apply iodine solution
  - > Spray bottle, dipping, or paint roller
  - > Cover cross section completely
- Wait for color change
- Score according to Generic Starch Chart (1 – 8 scale)
  - > Score to nearest ½ unit
  - > Calculate average to nearest 1/10th

Cutting Depth Affects Starch Iodine Score

Too High!

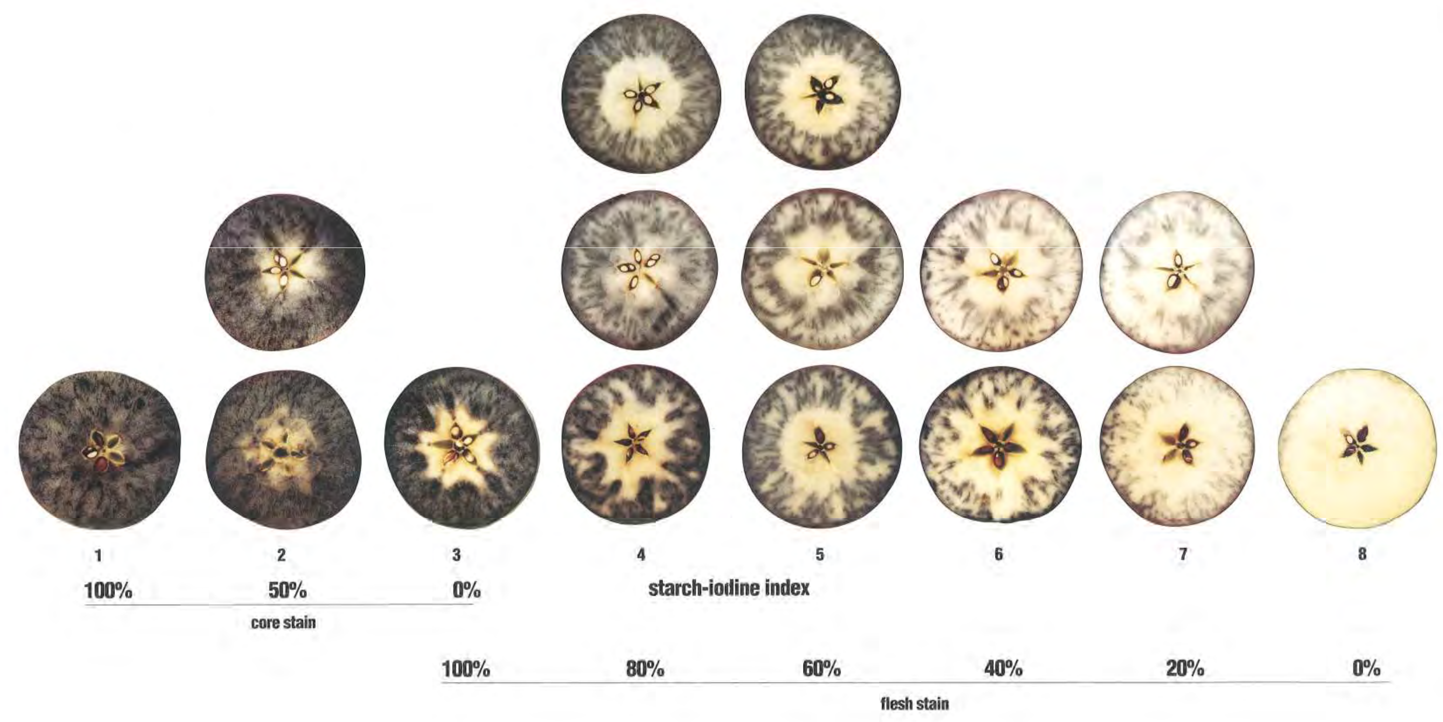
Correct

•Cut across seed cell cavities

AgroFresh

Harvista™

Generic Starch-Iodine Chart for Apples



Available from AgroFresh Account Managers

Source: Cornell Cooperative Extension Info Bull 221

Maturity Indexes Exaggerate Maturity Differences Among Blocks

Harvista

Maturity indexes prevailing on BHD* of eight McIntosh blocks in 1991

Farm	Best Harvest (Sept)	Internal Ethylene (ppm)	Firmness (lbs)	Soluble Solids (%)	Starch Index (1 - 8)
A	9	0.08	13.4	10.4	3.8
B	9	0.56	15.9	12.0	4.8
C	10	0.50	15.3	12.8	4.9
D	11	0.08	15.4	12.2	5.8
E	11	0.13	14.2	12.2	5.1
F	13	0.22	15.7	12.4	5.6
G	13	0.48	14.6	12.3	5.6
H	13	0.62	14.1	12.2	5.4

* Best Harvest Date as determined by taste panel

Source: Info Bull. 221, Blanpied and Silsby, 1992

Indicated Spread of Maturity According to Indexes

Index	Range	Approximate Rate of Change	Indicated Spread in Maturity
Pressure Test	2.5 lbs	1 lb per wk	2 ½ wks
Soluble Solids	1.6 %	0.5% per wk	3 wks
Starch Iodine	2.0 units	1 unit per wk	2 wks

Actual Spread of Maturity = 4 Days!

•Average readings from several blocks for regional recommendation
•"Out lying blocks" at both extremes cancel each other

Other Cautions

- Iodine is hazardous to handle
  - > Stains clothing and fabrics
  - > Avoid spills and unnecessary skin contact
  - > Perform testing in well ventilated areas
  - > Dispose of treated apples appropriately
- Extra iodine can be held over for next season
  - > Hold in darkened area
  - > Protect from freezing
  - > Weak solution slows reaction time of apples

Watercore in Apples: Causes, concerns, detection and sorting

Randy Beaudry, Department of Horticulture, Michigan State University

Watercore is a serious physiological disorder of apples that occurs on the tree. It is typified by water-soaked areas of the cortex, which cause the tissue to become translucent. In its mildest cases, watercore is localized near the primary vascular tissue running through the cortex (Fig. 1, upper left). The disorder is highly cultivar-dependent; however, watercore has been reported in most cultivars (Table 1). The symptoms can be radial in nature, often located near the vascular strands, or more coalesced in nature. These symptoms have been referred to "radial" and "block" watercore, respectively (Harker et al., 1999). In severe cases, it can encompass the entire core area of the fruit and result in liquid accumulation in the seed cavity (Fig. 1, upper right). In extreme cases, the water-soaked areas can even extend out to the surface of the fruit (Fig. 1, lower left) such that light passes readily through the cortex and skin (Fig. 1, lower right). Upon storage, watercore can dissipate, but in some cases, leads to the development if sometimes severe internal browning (Fig. 2).

Figure 1. Watercore. Internal injury can be mild or severe and can extend to the surface in severe cases, (lower right).

Figure 2. Internal injury caused by watercore following storage.

HISTORY

Watercore was, as far as has been determined, first described in published literature in 1886 by Paul Sorauer (Sorauer, 1886) in a German textbook entitled *Handbuch der Planzenkrankheiten*. Sorauer described the disorder as “glassy” flesh and called the disorder “glasige apfel”. He described the watercore tissue as being distinctly sweeter, firmer, having less intercellular air, having less starch, browning quicker, and smelling differently than the unaffected tissue. When Soraur published this description, it was evident that the disorder was widely recognized, but had not been the subject of serious research. [Note: terms used to describe watercore over the years include *glasige apfel*, *pommes vitreuses*, *la vitrescenza delle mele*, *glassy disease of apple*, *apple glassy disease*, *glassy core*, *watery-nose*, *pineapple centers*, and *water core* (Marlow and Loescher, 1984)]. By 1934, the favored term became watercore, although, for reasons made obvious by the lower right-hand image in Fig. 1, it is termed glassiness when the symptoms are visible from outside the fruit.

Early work in the U.S. was broadly distributed across the land-grant experiment stations and in semi-private and federal laboratories. O’Gara (1914), a pathologist and entomologist from Medford, Oregon, published several papers on the causes of watercore. He concluded that watercore was promoted by several environmental and biological factors including good fruit exposure, excessive or vigorous growth, well-cultivated soils, excessive precipitation or irrigation, extremes in temperature and humidity, severe pruning just before ripening, low temperatures (especially frosts) prior to harvest, factors that induce the rapid conversion of starch to sugars.

PHYSIOLOGY

Watercore is caused by the accumulation of sorbitol-rich liquid in the intercellular spaces of the apple tissue. As the liquid accumulates between the cells of the fruit, it reduces the scattering of light passing through the tissue, causing it to be translucent. The disorder only develops on the tree. Detection technologies using light transmission can successfully identify affected fruit at the time of harvest. However, the symptoms disappear during storage even though damaged tissue remains (Harker et al., 1999; Upchurch and Throop, 1994).

The liquid causing watercore is rich in sorbitol, which is the primary transport carbohydrate of apple (Marlow and Loescher, 1985; Fig. 3). Current evidence points to the cause of watercore being related to the unloading of photosynthate-rich liquid from the phloem cells of the vascular tissue that runs through the apple fruit. Normal sorbitol metabolism is impaired, but that o sucrose is not. In symptomatic tissues, the sorbitol-rich liquid of the phloem is somehow inhibited from being absorbed by the cells in the fruit cortex (Gao, et al., 2005), leading to the accumulation of the 'sap' unloaded from the phloem cells and a reduction in reducing sugars (fructose and glucose) in the fruit cortex. In normal tissue, the cells of the apple cortex likely have an excess capacity to absorb the unloaded phloem cell sap.

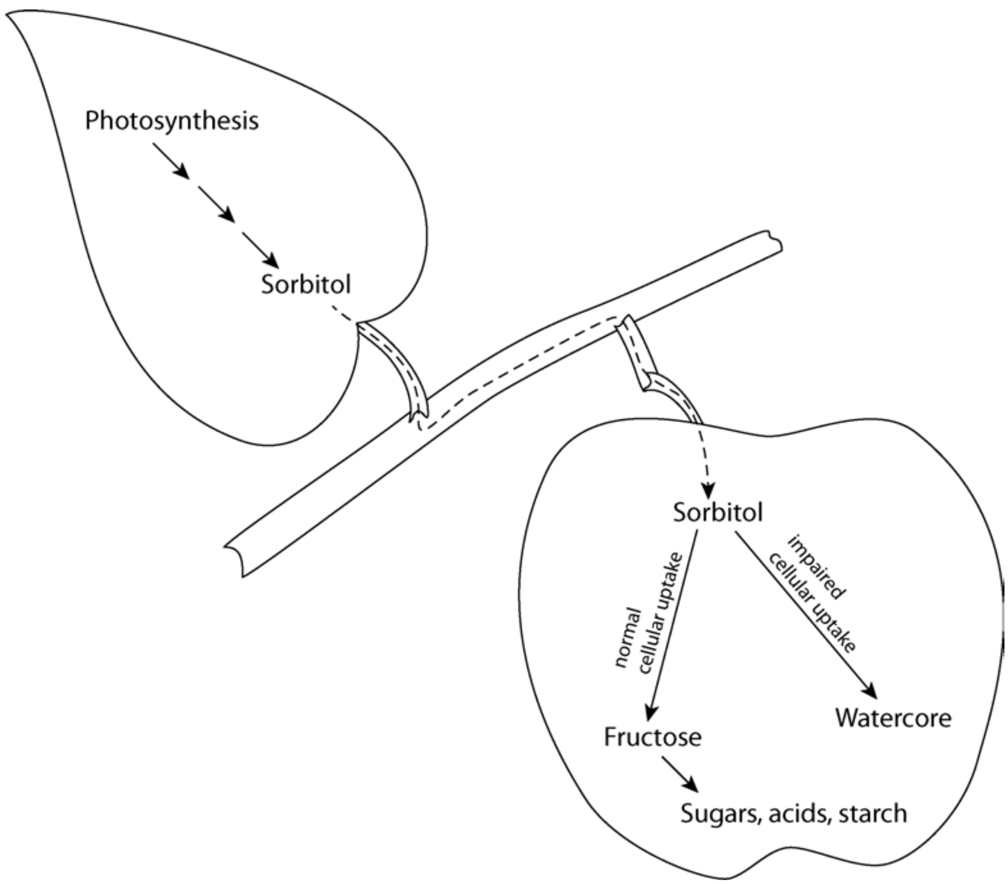


Figure 3. Route of sorbitol transport form source (leaf) to sink (fruit) and its contribution to watercore development (redrawn from Marlow and Loescher, 1984).

FACTORS AFFECTING WATERCORE

In their review, Marlow and Loescher (1984), summarize those factors historically linked to watercore development and evaluated their potential to be contributing factors. These include:

Water regime	Generally speaking, the amount of water available to the plant has not been shown to be a causative factor and is probably not linked. Excessive humidity around the fruit, however, may contribute to symptom development. A link between watercore development and late season rainfall has been attributed to the fact that rainfall delays harvesting, allowing the fruit to mature and become more prone to watercore development.
Temperature	High fruit temperatures are linked to watercore development, as are periods of low temperature (below 40 °F). The exposed side of the fruit, with higher day/night temperature fluctuations, may be more susceptible to disorder development. In that low temperatures can induce ripening in some varieties and that high temperatures drive more rapid fruit development, the effect of higher temperatures and/or low temperatures may be partly through induction of ripening and advancing the maturity of the fruit.
Mineral nutrition	High nitrogen levels have been linked to increased watercore incidence, but the relationship is not clear-cut. There is some indication that high nitrogen and low calcium may be important in watercore development, but conclusive data are lacking. Boron in excessive levels has been shown to induce watercore. This relationship may also be linked to fruit maturity in that boron at high levels can inhibit fruit drop and lead to advanced maturity of the fruit at the time of harvest. There appears to be a link between low calcium levels and watercore incidence, but the relationship is not strong. Interestingly, infiltration of fruit with calcium can inhibit symptoms. While calcium is known to have an impact on a number of processes in pome fruit, it's impact on slowing maturation of the fruit may be the most critical in the case of watercore development. Interestingly, the application of calcium may also impact watercore by influencing leaf senescence; slowing the aging process in leaves prevents the rapid export of sorbitol associated with the latter stages of life stages of leaves.
High source-to-sink ratio	A high source-to-sink ratio has been shown to have a marked impact of watercore development. Defoliation and girdling studies have shown that if the products of photosynthesis are in excess, as in the case of seasons with a short crop, the likelihood of watercore increases measurably. Linked to this, watercore has been found to be elevated in young trees bearing small crops, light crop loads or large-sized fruits, and excessive thinning. When the source-to-sink ratio is high, the fruit receives more photosynthate, allowing it to reach larger sizes and higher

levels of metabolites including acids and sugars. Furthermore, a high source-to-sink ratio can also accelerate maturation, which is associated with increased watercore incidence.

Maturation and ripening — While there are occasional references to watercore occurring in immature fruits (on the sunny side of the tree), the overwhelming evidence suggests that advanced maturity is a required feature for the development of watercore. Evidence also comes from the application of growth regulators that impact fruit ripening: ethylene applications enhance watercore and Alar (daminozide) diminishes watercore. The impact of maturation may be mediated through cell wall changes, loss in the integrity of cellular membranes, rapid breakdown of starch, and altered transport of photosynthate. Of these, the latter seems to have the greatest likelihood of being most directly associated with watercore development. Evidence suggests that when the tree produces elevated amounts of photosynthate (which is typically in the form of sorbitol) at a time when the capacity of the fruit cells to take up the sorbitol is diminishing (as it is during the latter stages of development), then the stage is set for symptom development.

POSTHARVEST CONSIDERATIONS

While watercore dissipates partially or even completely with storage, it tends to "weaken" fruit and make them more susceptible to degradation in storage and in the marketing chain. In addition, watercore makes fruit more susceptible to CO_2 injury (Park and Lee, 1991), probably due to a decrease in tissue permeability and the build-up of CO_2 and the induction of fermentation (Agenta et al., 2002). The low temperatures of storage slow the reabsorption of the free water between the plant cells and CA storage retards this process even further. It is thought that the effect of CA and low temperatures are through the inhibition of ripening (Marlow and Loescher, 1984). For this reason, there is some concern that 1-MCP may exacerbate the slowing of watercore dissipation even further. In one study, the ripening inhibitor 1-MCP has been reported to have no effect on dissipation of the symptoms of watercore in storage (Argenta et al., 2005), but other sources suggest the relationship is more complicated and 1-MCP may indeed slow dissipation and lead to greater internal browning in some cases (Watkins, 2007).

A scale has been developed for the purpose of judging the severity of watercore in fruit lots in order to determine whether the fruit should be sheld for short or long-term storage (Neuwald et al., 2010, Fig. 4). Slight water (0-2 on the six-point scale) was deemed "acceptable" and would be non-injurious in short- to medium-term storage.

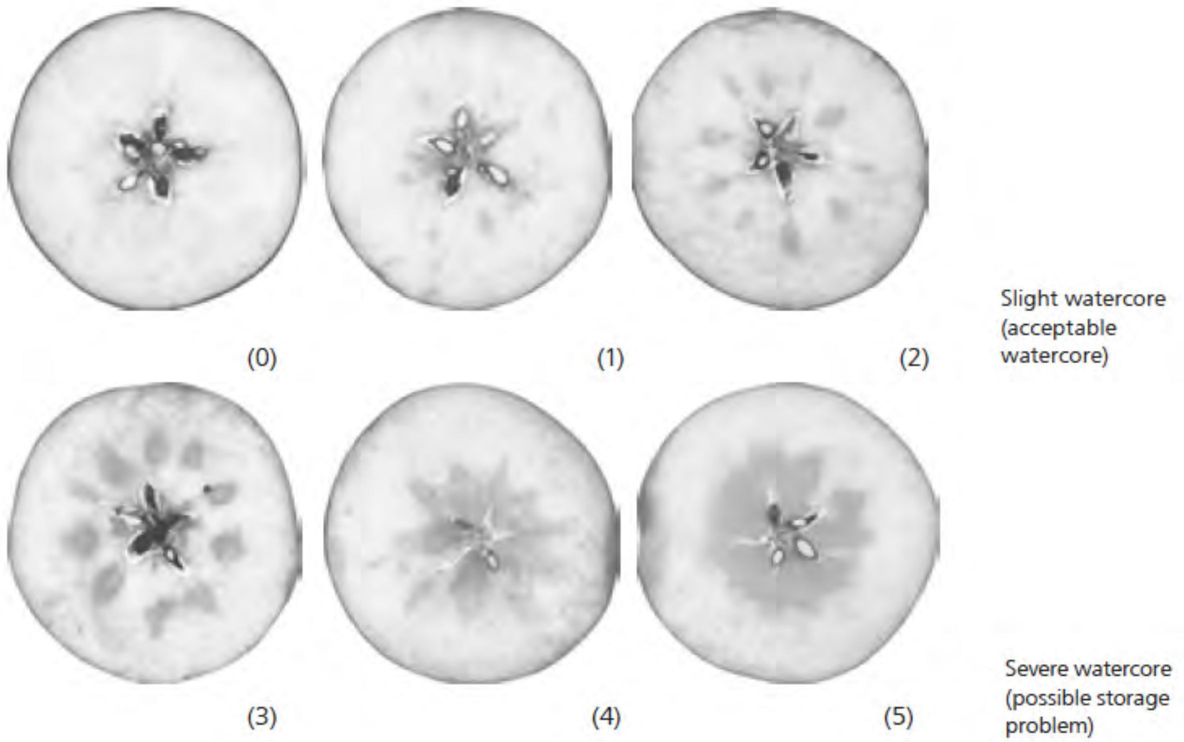


Figure 4. Reference images for scoring watercore severity on a range of 0 to 5 (o represents fruit without watercore and 5 is equivalent to 40% or more of flesh involvement.

DETECTION AND SORTING

Detection of watercore is possible using a number of techniques. Non-destructive detection techniques include light transmission, fruit density, nuclear magnetic resonance (NMR), X-ray computed tomography (X-ray CT), and thermography.

One method is detection and sorting based on the density of the fruit (Cavalieri et al., 1998). Fruit with watercore have a greater density (a.k.a. specific gravity) than fruit without watercore. The density of non-affected fruit typically ranges between 70% and 85% of the density of water, but the density of watercore-containing fruit is higher, between 90% and 95% that of water. This observation has lead to a simple means of detection and separation; fruit can be separated efficiently using a liquid of appropriate density - usually about 90% the density of water. This can be managed using chemical additives (typically alcohol) having a low density or using aeration (Fig. 5). In one method, fine air bubbles are introduced into the dump tank using a sparger and the reduced water density causes the watercore-affected fruit to sink below a sorting plenum and the unaffected fruit float above the plenum and are thereby separated. The problem with this technique is that fruit density varies from orchard to orchard and is a function of variety and fruit size, with larger fruit typically being less dense.

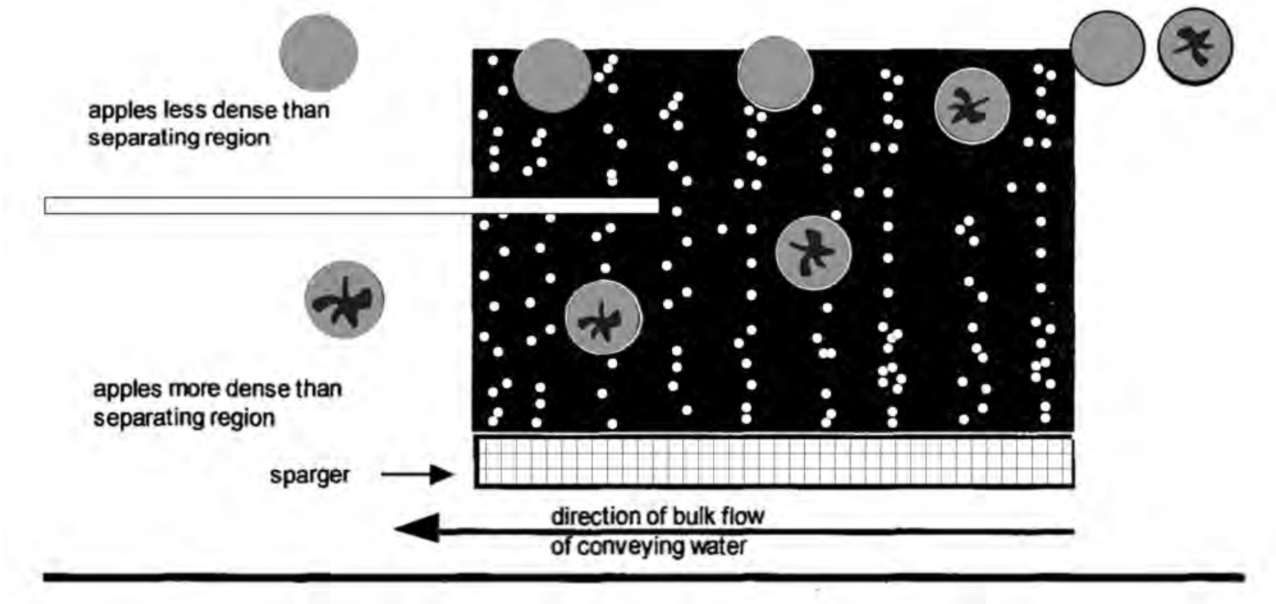


Figure 5. Schematic depicting the separation of less dense, non-watercore apples (upper stream of fruit - gray spheres) from more dense, watercore-containing fruit 9lower fruit stream) (redrawn from Cavalieri et al., 1998).

Use of light transmission through the fruit was an early method to detect watercore (Olsen et al., 1962; Throop et al., 1989). Light passes through the watercored tissue more readily than the non-symptomatic tissue, which tends to scatter the light. As a result, a greater portion of the incoming light passes through the fruit. Trebor Industries developed a hand-held device for detecting watercore on individual fruit using transmitted light. More recently, several companies (e.g. Greefa iFA, Compac TasteTech, Fig. 6) offer internal defect detection, which includes the ability to detect watercore (in addition to internal browning) using visible and near infrared (NIR) wavelengths. In these technologies, light is shone into the fruit and the loss in the intensity of light eimissions fromthe fruit (or lack thereof in the case of watercore) is determined, permitting rapid and effective sorting.

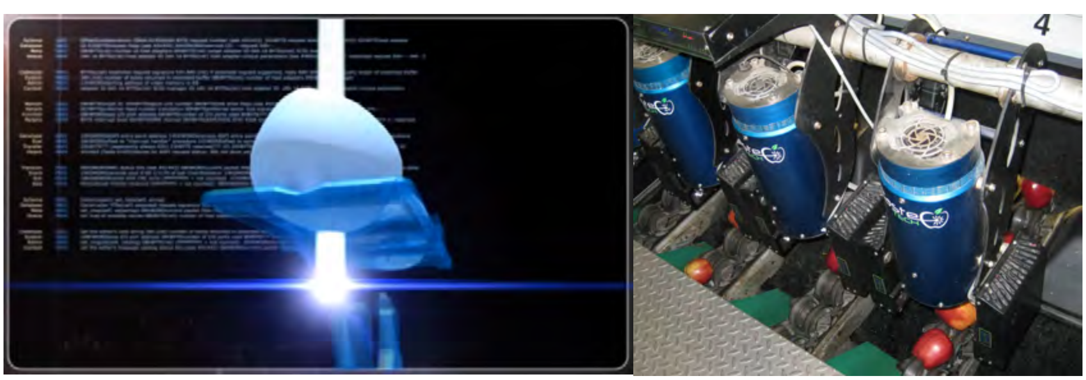


Figure 6. Images of Greefa (left) and Compac (right) technologies for internal defect detection and fruit sorting.

In addition to floatation and light transmission, a few more esoteric technologies have been investigated. Nuclear magnetic resonance (NMR) imaging (a.k.a. MRI) is a technique that can easily identify areas of free water in fruit or other tissues, wielding cross-sectional images (Fig. 7) in a few seconds to minutes time (Wang et al., 1988). While the technology is effective, it is too slow for practical applications requiring 10 or more fruits to be analyzed per second. Very high energy requirements are also a hindrance.

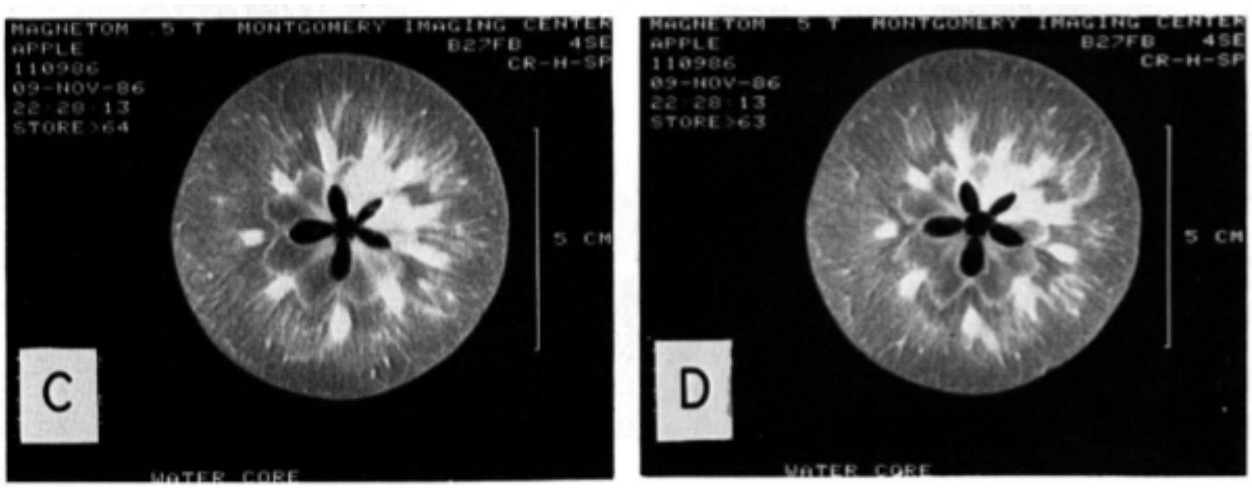


Figure 7. Nuclear magnetic resonance imaging of watercore in Red Delicious fruit (from Wang et al., 1988).

In a study comparing the effectiveness of X-ray computed tomography (X-ray CT) and MRI, the two technologies were similarly able to image and detect watercore in apple (Herremans et al., 2013, Fig. 8). Interestingly, the X-ray CT images could be used to image individual cells in the cortex and clearly show the accumulation of liquid between cells. The technique is slow, however, requiring several minutes to acquire a single image.

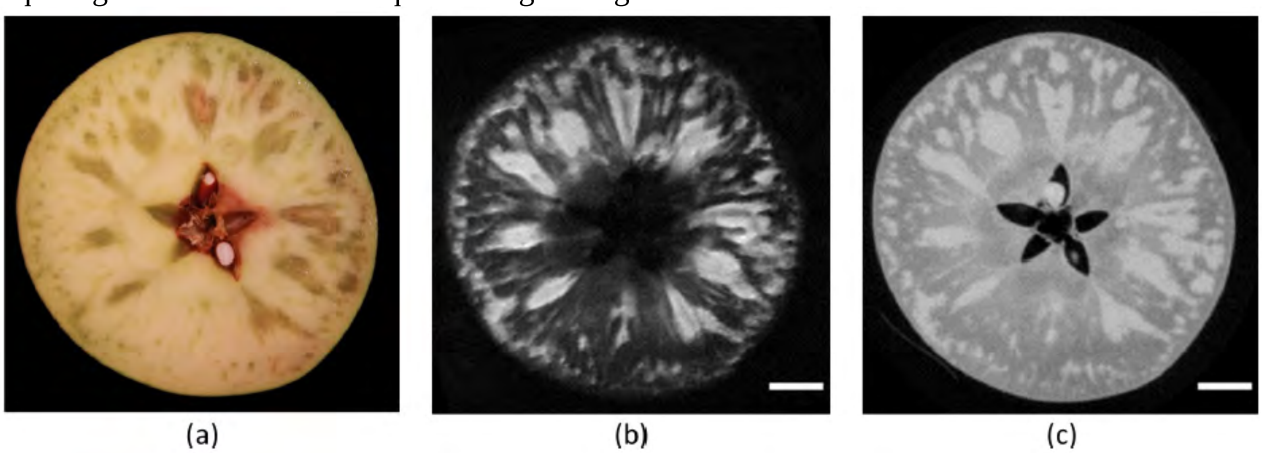


Figure 8. Watercore-containing 'Rebellon' apple fruit and its X-ray CT image (right) and MRI image (center).

Finally, thermal imaging can be used to detect watercore (Baranowski et al., 2008). This technique involves heating the fruit and measuring the rate of warming ising thermal images (Fig. 9).

Watercored fruit, likely because of the greater thermal mass and poorer air circulation, was slower to warm. While the technique is able to discriminate fruit correctly about 80% of the time, the time to acquire the data was over an hour and would be of little use in sorting. In addition, this technique requires precise temperature control, which is managed only with some difficulty.

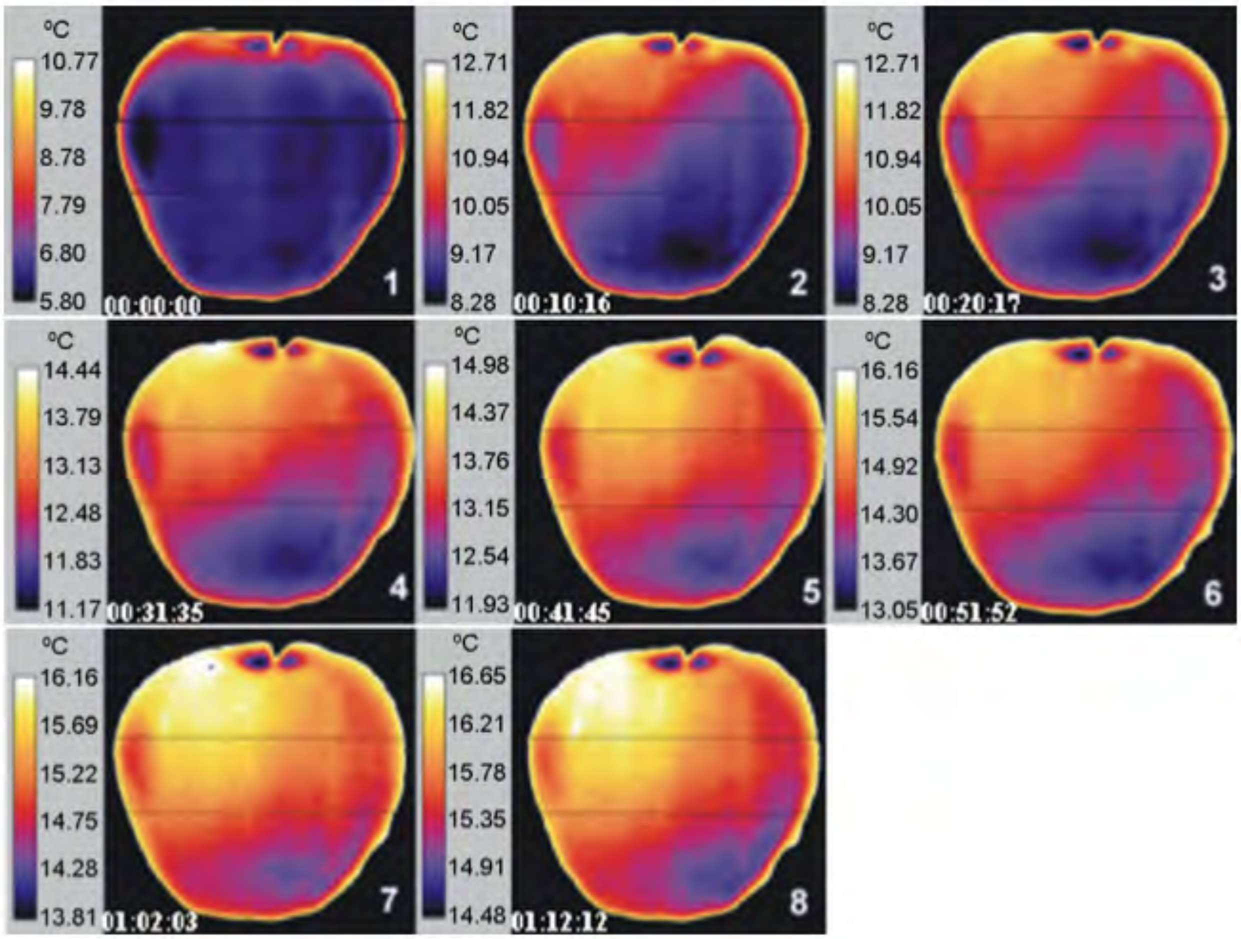


Figure 9. Thermography used for watercore detection (from Baranowski et al., 2008)

CONCLUDING COMMENTS

After more than a century of work, the root causes of watercore are still somewhat mysterious. While we know symptoms are linked to the fruit's inability to properly manage incoming photosynthate, the determining factor is still unknown. Importantly, though, we know that the disorder is linked to advancing maturity on the tree, so that further symptom development can be stopped simply by harvesting the fruit. While symptoms dissipate in air and CA storage, fruit with anything more than mild watercore symptoms should be marketed as soon as is practicable. Prior to storage and post-storage, detection and sorting can be rapidly performed with modern NIR sorting systems. The grower can minimize watercore development by establishing a balanced production system in which undercropping is prevented. In addition, a timely harvest before maturity becomes too advanced is critical in preventing this disorder from becoming too severe.

Table 1. List of cultivars with reported susceptibility (Yes) or resistance (No) to watercore (Marlow and Loescher, 1984).

Cultivar	Watercore susceptibility	Cultivar	Watercore susceptibility
Alfriston	Yes	Northwest Greening	Yes
Allington Pippin	Yes	Oldenburg	Yes
Antonovka	Yes	Ontario	Yes
Arkansas	Yes	Pioneer	Yes
Baldwin	Yes	Pound Sweet	Yes
Ballarat	Yes	Pumbkin Sweet	Yes
Beacon	Yes	Ramo	Yes
Ben Davis	Yes	Red Canada	No
Blenheim	Yes	Red Delicious	Yes
Braeburn	Yes	Red Miller	Yes
Bramley Seedling	Yes	Red St. Lawrence	Yes
Breton Henry	Yes	Reinette d'Angleterre	Yes
Calville Blanc	Yes	Rhode Island Greening	Yes
Cleopatra	Yes	Ribston Pippin	Yes
Commerce	Yes	Richared	Yes
Cortland	No	Rival	Yes
Cox's Orange Pippin	Yes	Rogers Red	Yes
Delicious	Yes	Rokewood	Yes
Democrat	Yes	Rome	Yes
Devonshire Quartredon	Yes	Rome Beauty	Yes/No
Dougherty	Yes	Roval Red	Yes
Duchess	Yes	Russian	Yes
Dunns	Yes	Scarlet Nonpareil	Yes
Early Harvest	Yes	Spitzenberg	Yes
Fall Pippin	Yes	Stark	Yes
Fameuse	No	Starking	Yes
French Crab	Yes	Starkrimson	Yes
Fuji	Yes	Statesman	Yes
Gano	No	Stayman	Yes
Gardner Red	Yes	Stayman Winesap	Yes
Glori Mundi	Yes	Stone Pippm	Yes
Golden Delicious	Yes/No	Sturdeespur	Yes
Granny Smith	Yes	Sturmer Pippin	Yes
Gravenstein	Yes	Suntan	Yes
Grimes Golden	Yes	Tasmans Pride	Yes
Holstein Cox	Yes	Tompkins King	Yes
Honeycrisp	Yes	Tolman	Yes
Irish Peach	Yes	Transparent	Yes
Jacobs Sweet	Yes	Turner Red	Yes
James Grieve	Yes	Twenty Ounce	Yes
Jardine Red	Yes	Verde Doncella	Yes
Jonathan	No/Yes	Virginia Summer Rose	Yes

King	Yes	Wagener	Yes
King David	Yes	Wealthy	Yes/No
Kinnard	Yes	White Astrachan	Yes
Lady	Yes	Willow Twig	Yes
Lalla	Yes	Winesap	Yes
Lane's Prince Albert	Yes	Winter Banana	Yes
London Pippin	Yes	Winter Golden Pearmain	Yes
Lord Derby	Yes	Wolf River	Yes
Lord Wolseley	Yes	Worcester	Yes
Margil	Yes	Worcester Pearmain	Yes
Mela Carlo	Yes	Yates	Yes
Miller's Seedling	Yes	Yellow Bellflower	Yes
Morgendotl	Yes	Yellow Newton	Yes
Mcintosh	No	Yellow Transparent	Yes
Newton	Yes	York Imperial	Yes
Northern Spy	Yes/No	Zurich Transparent	Yes

Literature Cited

Argenta, L.C., X. Fan, and J.P. Mattheis. 2002. Impact of watercore on gas permeance and incidence of internal disorders in 'Fuji' apples. Postharvest Biol. Technol. 24: 113-122.

Argenta, L.C., X. Fan, and J.P. Mattheis. 2005. Interactive Effects of CA Storage, 1-Methylcyclopropene and Methyl Jasmonate on Quality of Apple Fruit. Acta Hort. 857: 259-265.

Baranowski, P., J., Lipecki, W. Mazurek, and R.T. Walczak. 2008. Detection of watercore in ‘Gloster’ apples using thermography. Postharvest Biol. Tech. 47: 358–366.

Cavalieri, R.P., G.M. Hyde, and P.R. MacQuarrie. 1988. Hydraulic sorting of watercore apples. Acta Hort. 464:103-107.

Gao, Z., S. Jayanty, R. Beaudry, and W. Loescher. 2005. Sorbitol transporter expression in apple sink tissues: Implications for fruit sugar accumulation and watercore development. J. Amer. Soc. Hort. Sci. 130: 261-268.

Harker, F.R., C.B. Watkins, P.L. Brookfield, M.J. Miller, S. Reid, P.J. Jackson, R.L. Bieleski, and T. Bartley. 1999. Maturity and Regional Influences on Watercore Development and its Postharvest Disappearance in ‘Fuji’ Apples. J. Amer. Soc. Hort. Sci. 124: 166–172.

Herremans, E., A. Melado-Herrerosb, T. Defraeyea, B. Verlinden, M. Hertog, P. Verbovena, J. Vald, M. Encarnación Fernández-Vallee, E. Bongaersf, P. Estradeg, M. Weversh, P. Barreirob, B.M.Nicolaï. 2013. Comparison of X-ray CT and MRI of watercore disorder of differentapple cultivars. Postharvest Biol. Technol. 87:42-50.

Marlow, G.C., and W.H. Loescher. 1984. Watercore. Horticultural Reviews, 6:189-251.

Marlow, G.C., and W.H. Loescher, 1985. Sorbitol metabolism, the climacteric, and watercore in apples. J. Amer. Soc. Hort. Sci. 110:676-680.

Neuwald, D.A., D. Kitteman, and J. Streif. 2010. Watercore dissipation in Fugi apples at different holding temperatures. In: C. Nunes, ed., Environmentally Friendly and Safe Technologies for Quality of Fruits and Vegetables. Universidade Do Algarve.

O’Gara, P.J. 1914. The water core of apple. In: The Encyclopedia of Practical Horticulture, Vol. 1, G. Lowther and W. Worthington, eds., The Encyclopedia of Horticulture Corp., North Yakima, Wash.

Olsen, K, Schomer, H.A. and Birth, G.S., 1962. Detection and evaluation of watercore in apples by light transmittance. Proc. Wash. State Hortic. Assoc., 58: 195-197.

Park, Y.M., Lee, S.K., 1991. Susceptibility of 'Fuji' apples to low-oxygen injury and high-carbon dioxide injury during CA storage. J. Kor. Soc. Hort. Sci. 33, 38–43.
Sorauer, P. 1886. Handbuch der Planzenkrankheiten. 2te auflage. teil 1. Verlagsbuchhandlung, Paul Parey, Berlin. p. 142-143.
Throop, J.A., G.E. Rehkugler, and B.L. Upchurch. 1989. Application of Computer Vision for Detecting Watercore in Apples. ASAE. 32: 2087-2092.
Upchurch, B.L. and J.A. Throop. 1994. Effects of storage duration on detecting watercore in apples using machine vision. Trans. ASAE. 37:483-486.
Wang, S.Y., P.C. Wang, adn M Faust. 1988. Non-Destructive Detection of Watercore in Apple with Nuclear Magnetic Resonance Imaging. Scientia Hort. 35:227-234.
Watkins, C.B. 2007. The effect of 1-MCP on the development of physiological storage disorders in horticultural crops. Stewart Postharvest Review. 2:11 pp 1-6.

Pre-harvest ReTain® for Improved Post-harvest Quality

Byron Phillips • Valent USA Corporation

MSU CA Storage Clinic • August 6, 2014

ReTain Plant Growth Regulator from Valent BioSciences Corporation is an ethylene biosynthesis inhibitor. Specifically, it temporarily inhibits the enzyme ACC Synthase in the ethylene biosynthesis pathway. ACC synthase is a required precursor to internal ethylene production in climacteric fruit such as apples and pears. By inhibiting ACC synthase, *ReTain* delays fruit maturity.

ReTain has been used commercially in the U.S. since 1997. The primary use pattern has been as a harvest labor management tool for growers, and more recently to increase fruit set in walnuts and cherry. However, it also provides a number of post-harvest benefits for packing houses and processors by improving fruit condition, evening out maturity, reducing maturity related disorders, and reducing cullage.

Better fruit going into storage means better fruit coming out of storage that is firmer and has a longer shelf life. This has also resulted in a consumer preference for *ReTain*-treated apples.

ReTain has also shown good synergy with and better response to other storage tactics to maintain fruit quality such as low ethylene storage and post-harvest applications of 1-mcp.

Firmness

One of the benefits of *ReTain* applications on apple is firmer fruit at harvest, resulting in firmer fruit going into storage. The effects of that are carried through the storage period and post-storage shelf life as treated fruit not only starts out firmer, but also softens at a much slower rate than untreated fruit. The crunch associated with treated fruit has been specifically mentioned in consumer preference studies.

Maturity-Related Disorders

Delaying maturity reduces maturity-related disorders both in the field and in storage. *ReTain* reduces both incidence and severity of water core, stem bowl and internal ring cracking, cuticle greasiness, and internal “bleeding” of varieties like Romes and

IdaReds. Decay, mealiness, and internal breakdown are also reduced in storage. Further, storage scald can be reduced on varieties like Red Delicious and Granny Smith as delayed harvest provides more time for the accumulation of 100 hours below 50° F.

Uniform Maturity

Because it acts on a very specific point in the ethylene biosynthesis pathway, *ReTain* helps to even out maturity of apples as they reach this point at different times. More uniform maturity results in better segregation of fruit at the receiving dock, better storage decisions, and more consistent CA rooms.

Better Results from Subsequent 1-MCP Applications

Tighter, more uniform maturity also improves the response of subsequent 1-mcp applications. Since the commercial introduction of 1-mcp in 2002, a number of studies have shown the two chemistries to be synergistic. Effectiveness of 1-mcp is greatly influenced by fruit maturity at the time of treatment. As *ReTain* helps to even out fruit maturity, the response to 1-mcp is more consistent and improved. Both products used together in a program approach provide much better results than either product used alone.

Consumer Preference

In double-blind taste tests conducted by The National Food Lab in 2010, consumers showed a strong preference for *ReTain*-treated Galas and Red Delicious. Consumers rated treated Galas significantly higher for aroma, sweetness, and crunchiness; and treated Reds significantly higher for flavor, texture, juiciness, and crunchiness.

In the Pacific Northwest, packing houses and sales desks have both recognized the storage and post-storage advantages of *ReTain*-treated apples. Most packing houses encourage their growers to use *ReTain*, and at least one requires its use on certain varieties.