2005 CORNELL FRUIT HANDLING AND STORAGE NEWSLETTER

Items of Interest for Storage Operators
in
New York and Beyond

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Storage Disorders of Apples with and without 1-MCP (SmartFresh™)

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Introduction

Apple fruit are susceptible to a wide range of physiological disorders, depending on variety, maturity, nutritional status of the fruit, storage conditions such as air and controlled atmosphere (CA), and storage length. Many of these disorders are also affected greatly by the growing season. For example, chilling injuries tend to be greater in years with cooler than normal growing conditions, while hot and dry summers can be associated with higher incidences of external carbon dioxide injury, superficial (storage) scald and senescent breakdown.

The advent of a new technology such as 1-MCP results in extra scrutiny of the apple crop. There is a tendency to assume that any disorders present after storage have resulted from the use of the new technology, or that the technology increased the severity of the disorders. This has been particularly true in the last two years when the New York industry has had a higher than normal incidence of internal browning disorders. Therefore, a major focus of our research program has been to investigate the effects of 1-MCP on physiological storage disorders.

I. Browning or chilling-related injuries

Internal browning disorders are of significant concern for McIntosh and Empire apples, One of the reasons that higher storage temperatures are recommended for these varieties than for many others is that McIntosh and Empire are known to be susceptible to chilling injury. Nevertheless, there has been a tendency to store fruit at slightly lower than optimal temperatures in order to take advantage of beneficial effects of lower temperatures on flesh firmness. This has been especially true in the Hudson Valley where warmer growing conditions appear to provide greater resistance against chilling injuries. Even in the Hudson Valley, however, problems can occur if the storage period is excessively prolonged or in years with poor growing conditions. For example, in 1992 a cloudy and cold summer was associated with major fruit losses throughout the industry.

Browning problems in McIntosh and Empire are expressed quite differently. In McIntosh, the browning disfigures the fruit and makes it unsaleable, even when the severity is low (Fig. 1). In contrast, for Empire, the early symptoms are often very slight, can be associated with the upper shoulder part of the fruit, and may not be noticed by an apple consumer (Fig. 2). However, with the growing importance of the fresh cut industry for Empire, even small amounts of browning become critical.

Our goal is to establish postharvest storage strategies that the industry can use to avoid browning problems. In the 2004 harvest season, we focused on investigating the effects of oxygen on McIntosh, and oxygen and carbon dioxide on Empire in relation to storage

temperature. In all experimental treatments we included pre-storage treatments with 1000 ppm DPA and/or 1 ppm 1-MCP.

Fig. 1. A range of internal browning symptoms in McIntosh apples.

Fig. 2. Range of browning symptoms in Empire apples

Experiments with McIntosh

Fruit from the Cornell Orchards were exposed to oxygen at 2 and 3% and temperatures of 33 and 36°F for 4 and 8 months.

Few disorders were found at the 4 month storage removal time, but by the 8 month removal, the incidence of browning had become severe. The main effects of storage temperature, oxygen concentration, 1-MCP and DPA on flesh browning (%) and firmness (lb) are shown in figs. 3 and 4, respectively.

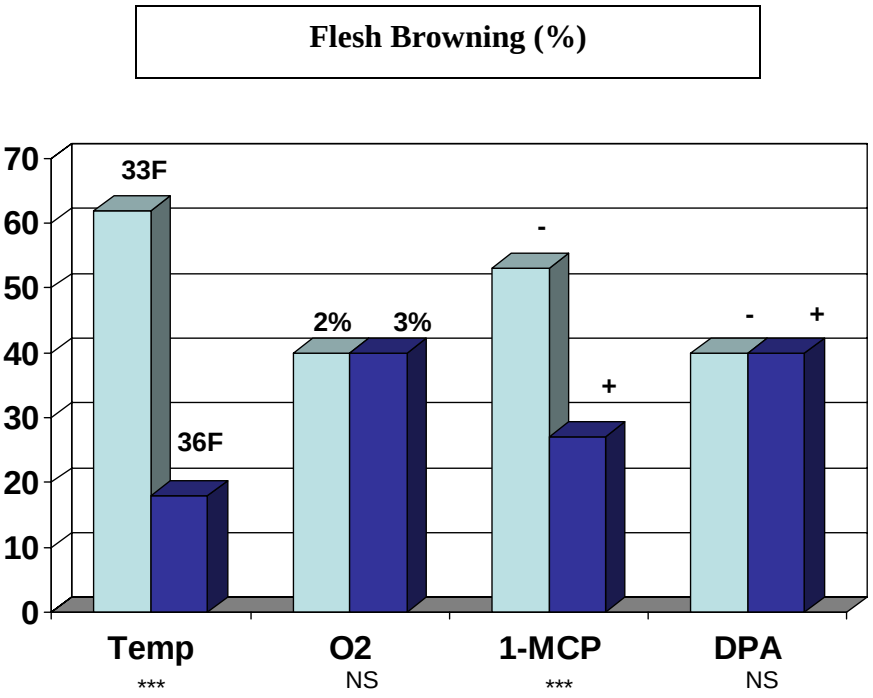

Fig. 3. The effects of temperature, oxygen concentration, 1-MCP and DPA on the percentage of flesh browning in McIntosh apples stored in CA for 8 months plus 7 days at 68°F.

Both raising the temperature from 33 to 36°F and treating the fruit with 1-MCP reduced the percentage of flesh browning. There was no effect of oxygen or DPA treatment. Within the different treatment combinations, however, only 2.5% browning occurred in fruit stored with 3% oxygen, plus DPA and 1-MCP at 36°F.

The reason that the industry wants to use lower temperatures for storage is to maintain flesh firmness, as without required firmness demanded by the marketplace the fruit become unsaleable. 1-MCP appears to allow use of higher oxygen concentrations and higher storage temperatures without loss of quality (Fig. 4).

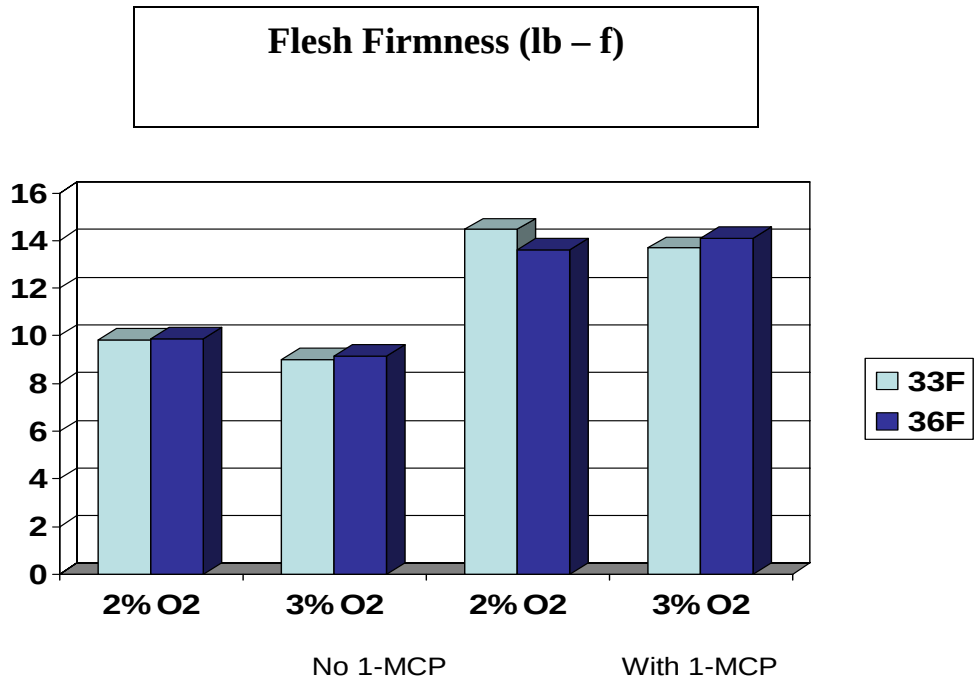

Fig. 4. The effects of temperature, oxygen concentration, and 1-MCP on the firmness (lb-f) of McIntosh apples stored in CA for 8 months plus 7 days at 68°F.

Experiments with Empire

Fruit from the Cornell Orchards were exposed to oxygen at 2 and 3% and temperatures of 33 and 36°F for 4.5 and 9 months.

There was little browning at 4.5 months, but after 9 months of storage, the levels of browning were high in all treatments. Although significant effects of temperature, oxygen concentration, 1-MCP and DPA were detected (Fig. 5), these were small and not commercially significant. The least browning occurred in fruit not treated with DPA or MCP and stored at 36°F, but these fruit were still unacceptably damaged (60% browning) and firmness was not acceptable. Although much of this browning was slight, its presence was severe enough to prevent any use for fresh cut slices. Unfortunately, we were not able to investigate a warmer temperature such as 38°F to determine if warmer temperatures would have reduced browning further.

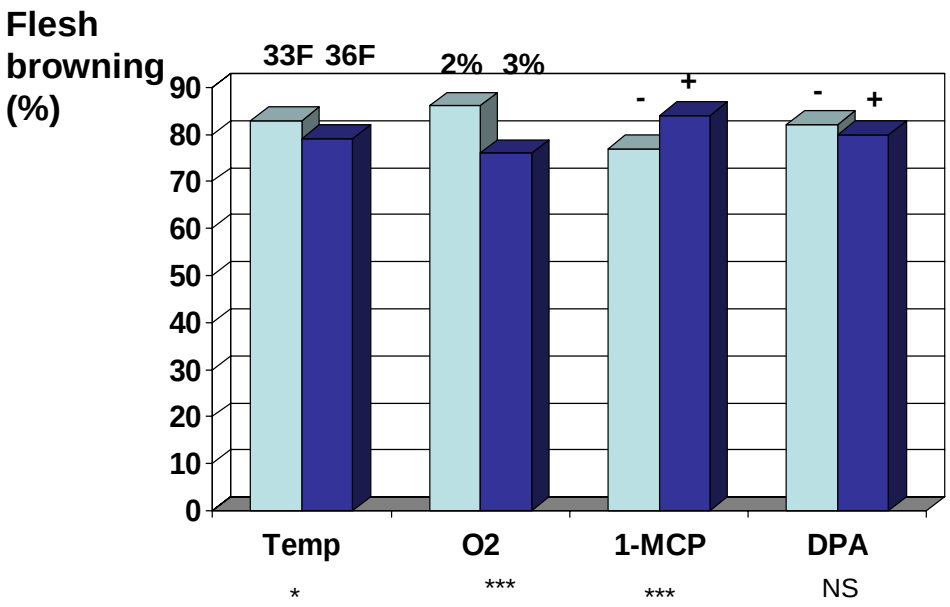

Fig. 5. The effects of temperature, oxygen concentration, 1-MCP and DPA on the percentage of flesh browning in Empire apples stored in CA for 9 months plus 7 days at 68°F.

We also investigated the effects of carbon dioxide on fruit from two harvests. Fruit for the first harvest had 0.098 ppm internal ethylene, 11.2% SSC, 4.8 starch index, and firmness of 15.7 lb, while fruit from the second harvest had 13.4 ppm internal ethylene, 12.3% SSC, 6.4 starch index, and firmness of 14.3 lb.

Fig. 6 shows the percentages of flesh browning of fruit from both harvests for the main effects of carbon dioxide concentration, temperature, 1-MCP and DPA. In fruit from harvest 1, browning was slightly reduced in fruit stored in 3% carbon dioxide compared with those in 1% carbon dioxide, and markedly reduced by 36°F compared with 33°F. There was no effect of 1-MCP or DPA on browning. The effect of fruit maturity was very high and overwhelmed any possibility of detecting the effects of any treatment.

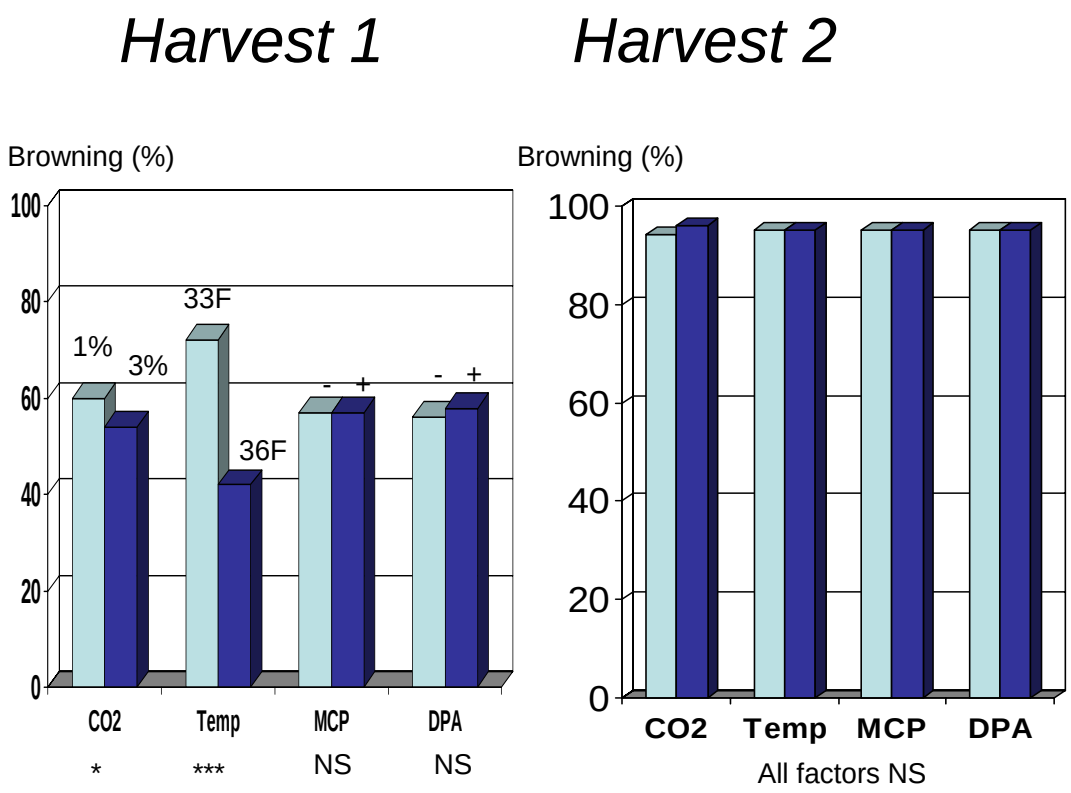

Fig. 6. The effects of carbon dioxide concentration, temperature, 1-MCP and DPA on the percentage of flesh browning in Empire apples from an early and a late harvest stored in CA for 9 months plus 7 days at 68°F.

Preharvest factors

In conjunction with Terence Robinson and Steve Hoying, we have initiated a number of trials to examine the effects of preharvest factors on browning. The results to date are not conclusive. For example, while investigating the effects of Retain sprays on the incidence of browning of McIntosh fruit grown in Western New York and Northern New York, we found that ReTain or postharvest 1-MCP treatment could increase browning incidence, especially in fruit from Northern New York, but in combination, there was less browning. The effect of harvest date was small in fruit from Western New York, but massive in fruit from Northern New York (Figs. 7 and 8).

Another experiment has examined the effects of pruning and shade at a Geneva site. The results indicate that browning was decreased in fruit that were late summer pruned or shaded, compared with fruit from the untreated control trees (Table 1). 1-MCP treatments increased browning incidence in that trial. However, another trial set up by a grower suggests that browning incidence was worse in pruned trees than in control trees, but there was no 1-MCP comparison in the grower trial.

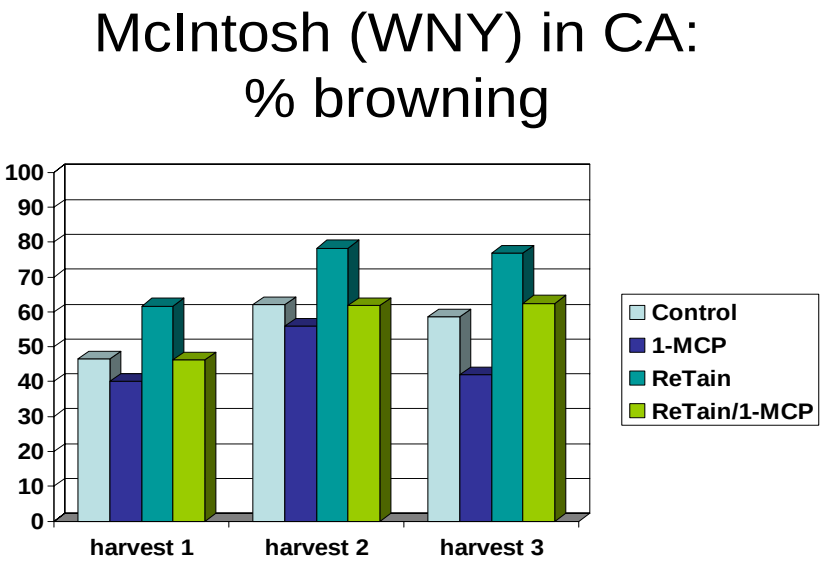

Fig. 7. Flesh browning (%) in fruit from three weekly harvest dates in Western New York, either treated with ReTain before harvest and/or a postharvest treatment with 1-MCP.

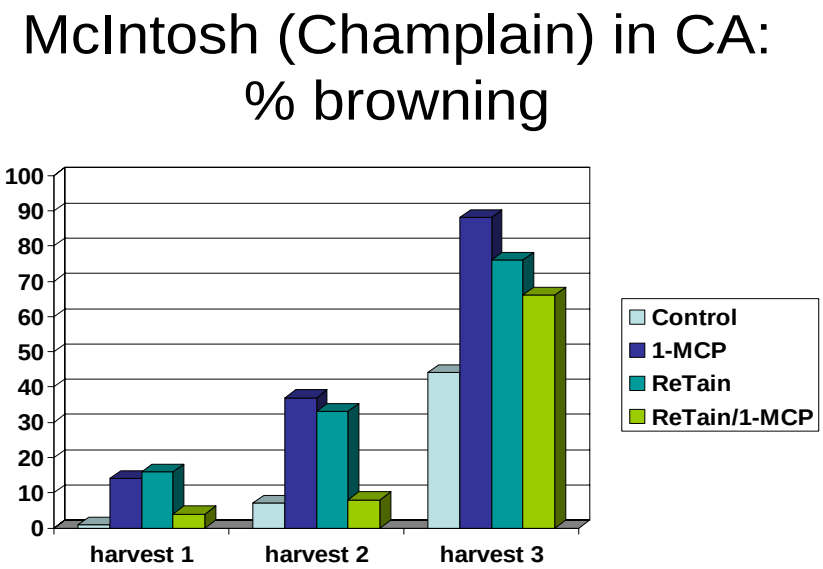

Fig. 8. Flesh browning (%) in fruit from three weekly harvest dates in Northern New York, either treated with ReTain before harvest and/or a postharvest treatment with 1-MCP.

Table 1. Maturity at harvest and percentages of flesh browning and external carbon dioxide injury in Empire apples either untreated (control), summer pruned (SP), or shaded (25% and 65%). [Robinson et al.]

Trt	IEC (ppm)	Starch Index	SSC (%)	Firmness (1b)	Flesh browning (%)		Ext CO2 injury (%)	
					- MCP	+ MCP	- MCP	+ MCP
Control	0.56	5.3	11.3	15.6	32	41	33	33
SP	2.27	5.4	11.2	15.6	17	37	6	16
25% shade	0.29	5.9	10.4	15.6	8	14	6	12
65% shade	0.17	6.3	10.6	15.9	8	33	9	10
1-MCP avg					16	31*	14	18^{NS}

Summary

We have not found immediate solutions for the browning problems that are likely to occur in a year with high chilling-injury risk. However, temperature and harvest maturity appear to be major factors. Our recommendations can only be tentative, but we suggest:

1. In a "chilling injury year", use 3% oxygen as your target atmosphere and raise storage temperatures as high as your dare towards 38°F.
2. In a "non-chilling year", use of higher oxygen is still advocated, but temperatures may be closer to the normal 35-36°F range. Rapid cooling and rapid 1-MCP treatment may be essential in both cases.

In either scenario, decisions must be based on experience, the storage period, and whether or not 1-MCP is used.

Our results indicate that preharvest factors play an important role in susceptibility of fruit to flesh browning. However, further research, especially on the effects of summer pruning, is required.

II. External carbon dioxide injury

Increased susceptibility of 1-MCP treated Empire apples to external carbon dioxide injury has been a concern for the industry. We have provided two recommendations:

1. Treat fruit with DPA (applied as a scald-control chemical) to eliminate risk.
2. Maintain carbon dioxide levels lower than 0.5 to 1% for the first 4 to 6 weeks of CA storage.

However, some storage operators still had losses when they used the non-DPA option. In general DPA is used extensively throughout the industry. While the DPA option is clearly the safest one available, we are still investigating how to control injury without use of the chemical.

A series of trials were carried out in 2004.

1. Differences among orchard susceptibility to injury.

The effects of 1-MCP on carbon dioxide injury are not always significant (Fig.9). While the susceptibility of fruit to injury varied greatly among orchards, often 1-MCP treatment had no effect on injury levels of the fruit.

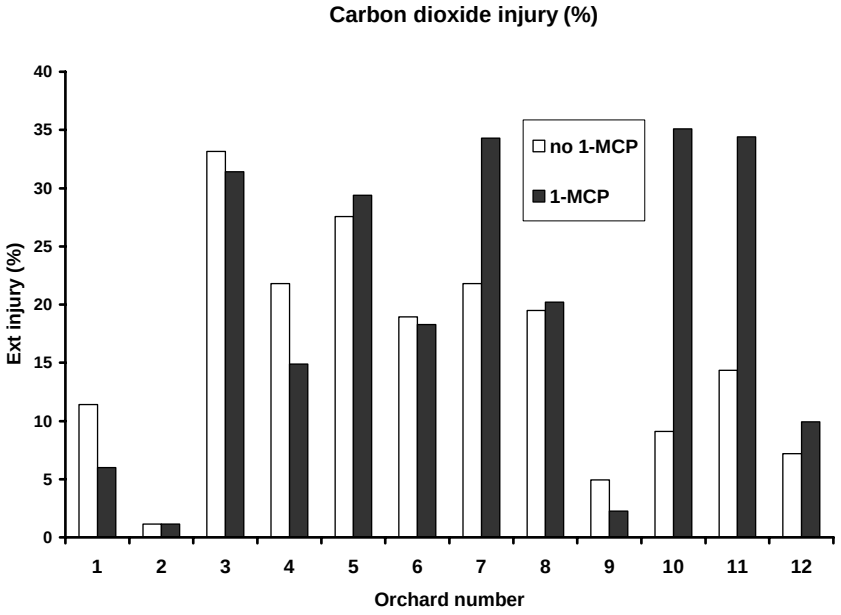

Fig. 9. Percentage of external carbon dioxide injury in fruit from 12 orchards untreated or treated with 1-MCP and exposed to 2.5% carbon dioxide (2% oxygen) for 20 weeks, plus 7 days at 68°F.

2. Timing of exposure of fruit to elevated carbon dioxide

The recommendation to the industry is to minimize risk of carbon dioxide injury by maintaining low carbon dioxide levels around the fruit for the first 4-6 weeks of storage. We have not been sure, however, if 1-MCP treatment

extends the period of susceptibility to injury, and therefore an experiment was carried out to test different timing of exposure of fruit to 2.5 and 5% carbon dioxide (in 2% oxygen). At all other times, fruit were exposed to 1% carbon dioxide. The exposure periods were 0-3, 4-6, 7-9, 10-12 and 13 to 20 weeks after the initiation of storage.

In a second experiment, fruit were exposed to constant levels of the three carbon dioxide atmospheres for 20 weeks. As expected, the relationships between injury incidence and carbon dioxide concentration is marked (Table 2). A smaller, but significant, effect of 1-MCP on injury at all carbon dioxide concentrations was also detected.

Table 2. External carbon dioxide injury (%) in Empire apples exposed to 1, 2.5 and 5% carbon dioxide for 20 weeks.

Carbon dioxide (%)	External carbon dioxide injury (%)	
	- MCP	+ MCP
1	4	8
2.5	25	38
5	31	57

Effects of CO_2 and MCP treatment significant at $P<0.001$ and $P = 0.011$, respectively.

The important observation of the first experiment is that 1-MCP does not appear to increase the susceptibility period for injury: The maximum period of injury was during the first 3 weeks of storage, irrespective of carbon dioxide concentration and 1-MCP treatment (Table 3). We have not altered our recommendation that carbon dioxide concentrations should be maintained as low as possible for the first 4-6 weeks. However, the change last season to encourage as low as 0.5% carbon dioxide in then storage atmosphere during this time is reinforced, if DPA is not used.

Table 3. External carbon dioxide injury (%) in Empire apples exposed to 2.5 or 5% carbon dioxide at different intervals during a 20 week storage period. Fruit were maintained in 1% carbon dioxide during the other periods.

Exposure time (weeks)	External carbon dioxide injury (%)			
	2.5% carbon dioxide		5% carbon dioxide	
	- MCP	+ MCP	- MCP	+ MCP
0-3	32	33	34	43
4-6	7	6	3	8
7-9	5	8	7	6
9-12	5	3	4	3

Effect of exposure time significant at $P < 0.001$.

3. Long term carbon dioxide concentrations in the storage atmosphere

The other issue with respect to carbon dioxide injury is how important it is for the carbon dioxide levels to increase after the initial period of low concentrations. The Cornell recommendation is for a concentration of 2-3% to maintain firmness, but is carbon dioxide necessary if fruit have been treated with 1-MCP?

In 2002 and 2003 we carried out a series of trials to investigate prolonged exposure to carbon dioxide concentrations from 0 to 5%. There was little effect in the 2003 trial, but in 2002 we observed that the effect of carbon dioxide in the storage atmosphere was greatly affected by 1-MCP (Fig. 10). Without 1-MCP treatment, fruit were softer at 0 and 1% carbon dioxide, slightly so at 3 months of storage, but markedly so after 7 months of storage. With 1-MCP, the benefit of carbon dioxide in the storage atmosphere was absent. Therefore, we are less concerned about increasing carbon dioxide in the storage atmosphere for 1-MCP treated fruit, but a cautionary note; if fruit in the storage room are not uniformly responsive to 1-MCP then maintaining low carbon dioxide concentrations over extended periods will compromise their quality.

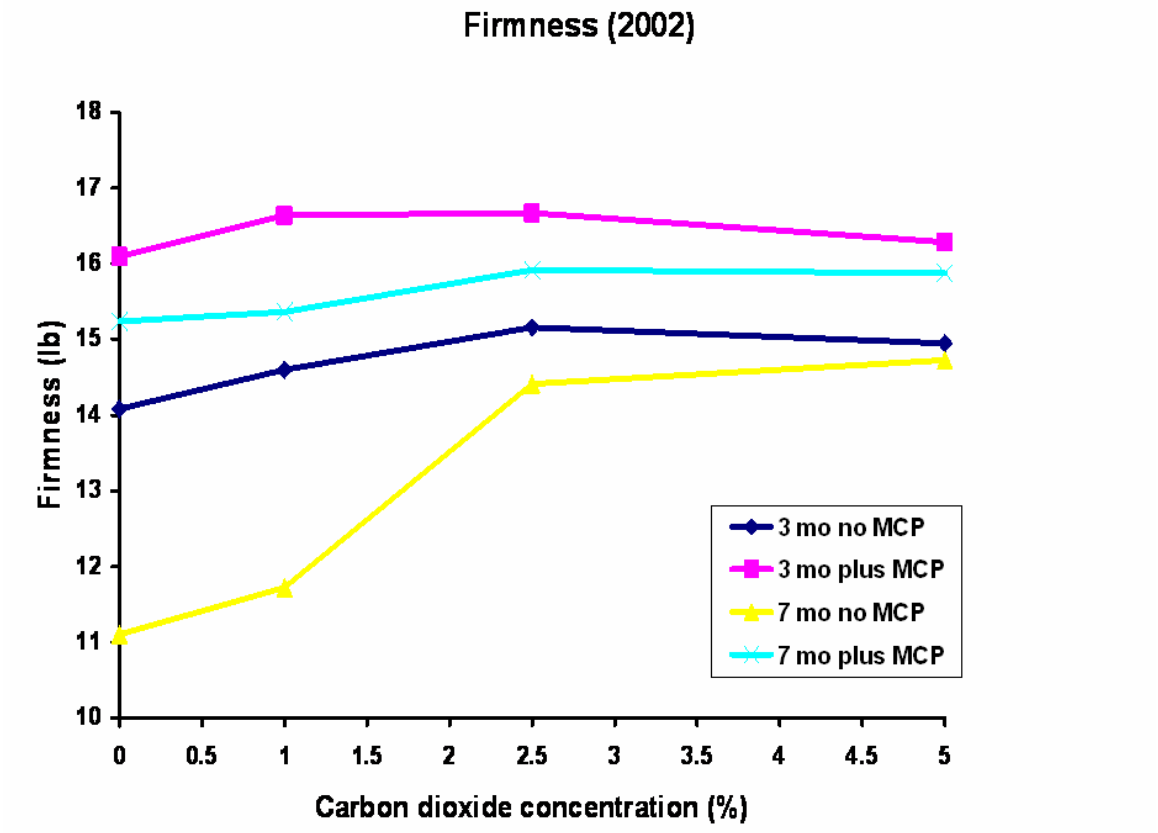

Fig. 10. Firmness (lb) of Empire apples either untreated or treated with 1-MCP and then stored in a range of carbon dioxide concentrations (2% oxygen) for 3 and 9 months.

Final comments about carbon dioxide injury

DPA remains the no-risk strategy until we find alternative methods for control of external carbon dioxide injury. It allows piece of mind and relieves concern about any carbon dioxide changes in the storage atmosphere either initially or over time. Do not "double dip" and use low carbon dioxide strategies if you have used DPA, however.

III. Superficial scald

We do not have new information over that presented at the last workshop. In summary, control of superficial scald by DPA appears excellent in Delicious. Control of scald by 1-MCP can also be very good for other varieties, including McIntosh, Cortland and Law Rome, but we often see examples of incomplete control. If the effects of 1-MCP on ethylene and firmness wear off then the benefits of scald control will also be lost. Therefore, we recommend that you continue using DPA for most varieties, but encourage you to leave small quantities untreated until you gain experience relevant to your storage situation.

IV. Watercore

There are reports that 1-MCP will reduce the rate of watercore loss from fruit. During this past season we carried out a preliminary experiment with Fuji, and found a slight effect of 1-MCP on watercore incidence and severity during storage (Fig. 11). We recommend that fruit with watercore at harvest should not be treated with 1-MCP.

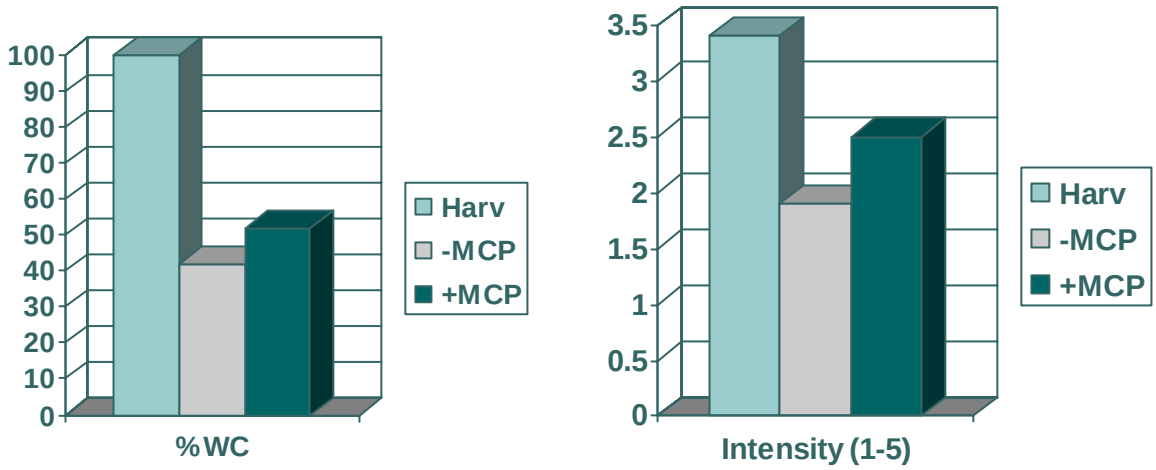

Fig. 11. Watercore incidence and intensity for Fuji apples untreated or treated with 1-MCP at harvest and stored at 33°F for 4 months.

Recent Studies on Inoculum sources for *Penicillium expansum* and Implications for Controlling Blue Mold Decay of Apples

David A. Rosenberger and Anne L. Rugh

Epidemiological studies were initiated in the mid-1990's to identify inoculum sources for *P. expansum* and sanitation methods that could be employed to reduce inoculum levels. Contaminated field bins were shown to carry huge quantities of inoculum from one season to the next, with some bins carrying more that 10^9 spores per bin (Table 1). Spores on contaminated bins are washed off of the bins when the filled bins are given postharvest drenches the next fall. Inoculum that accumulates in the drench solution contributes to increased decay, thereby producing even dirtier bins for use during the next season. Sanitizing bins has been shown to remove 99% of viable conidia, but few packinghouses routinely sanitize bins because of the costs involved in doing so and questions about the economic benefits of bin sanitation.

Although field bins are recognized as a major inoculum source for *P. expansum*, no one knew the relative importance of recycled inoculum from field bins as compared to "new" inoculum originating from the field each year. The effort to sanitize field bins might be wasted if similarly large quantities of inoculum could be brought into the storage each year via contaminated apples or via soil stuck on the runners of field bins. Therefore, we initiated work to quantify populations of *P. expansum* that could be found in orchard soil and on apples at harvest time.

Table 1. Numbers of viable *Penicillium* spores per bin that were released into wash water as determined by washing bins with a portable drencher and dilution-plating sub-samples from the wash water.

Summer 1999	Number of spores per bin recovered in wash water[1]
Group I non-sanitized oak bins	8.35×10^8
Group I following fresh sanitizer wash	1.54×10^6
Group I washed at the end of sanitizer usefulness	7.44×10^6
Group II non-sanitized oak bins from another CA room	4.25×10^8
Summer 2000	
Wooden bins (mixed oak and other wood)	2.23×10^9
Plastic bins from the same storage room	4.82×10^8

[1]Means were derived from washing five replicates of 5 bins each in 1999 and four replicates of five bins each in 2000. Most bins contained decayed apples that were not removed prior to washing.

Quantification of *P. expansum* in orchard soils: Soils from five different apple orchards near Highland, NY, were sampled at various times in 2004 and 2005. In the four orchards that were being actively managed, soil was collected from the herbicided area beneath the tree canopy. The fifth orchard had been abandoned roughly 20

years ago and was largely overgrown with weeds, brambles and other shrubs. In each orchard, samples were collected from within the drip-line of five different trees that were separated by at least 10 meters. Soil was sampled by removing surface debris and/or cover plants with a shovel and then collecting approximately 50 cc of soil from the upper 8 cm of the soil profile at five different locations beneath each tree. The five sub-samples from each tree were mixed together, but the bulked sub-samples from each tree were evaluated separately to provide five replicate evaluations from each orchard. The samples were taken to the lab and the density of *P. expansum* in the soil samples was estimated via dilution plating on a selective agar medium.

Density of *P. expansum* in orchard soils ranged from 14 to 218 colony forming units (cfu) per gram of dry soil in the managed orchards but were roughly 10 times higher than that in the abandoned orchard (Table 2). Spore density in orchard soils were surprisingly consistent from year to year in the four orchards soils that were evaluated in both 2004 and 2005.

Table 2. Preliminary results from sampling orchard soils in the Hudson Valley to determine populations of *P. expansum* and proportions of the populations that were benzimidazole-resistant.

Orchard	sampling date	cfu *Penicillium* species per g soil: all species	cfu *Penicillium* species per g soil: P. expansum	*P. expansum* as a percent of total *Penicillium* population	% *P. expansum* with benzimidazole resistance	Estimated *P. expansum* spores per bin assuming 1 kg soil/bin
A	23-Jul-04	262	33	12.6	27	33,000
A	17-Jun-05	1008	218	21.6	24	218,000
B	3-Sep-04	3,440	182	5.3	0	182,000
B	17-Jun-05	1626	186	11.4	1	186,000
C	30-Jun-04	298	14	4.7	8	14,000
C	9-Jun-05	698	46	6.5	10	46,000
D	19-Jul-05	310	40	12.9	13	40,000
E	8-Sep-04	15,268	2,137	20.6	0	2,137,000
E	16-May-05	5,447	1610	29.6	0	1,610,000

We assumed that even in a worst-case scenario involving wet harvest weather with soil occasionally balled into the bin runners, bins would be unlikely to carry more than a mean of 1 kg of soil into drench solutions. Given that assumption, the contribution of orchard soils to build-up of *P. expansum* inoculum in postharvest treatment solutions is dwarfed by the inoculum that can originate with badly contaminated bins (Table 1). Contaminated bins can carry 10,000 times more inoculum than a kilogram of soil from the managed orchards that we tested and more than 1000 times more inoculum than would be contained in a kilogram of soil from the abandoned orchard we tested. The higher inoculum levels in the abandoned orchard is

probably attributable to higher levels of decaying organic matter on the soil surface, but fungicide use in managed orchards might be another factor that affects populations of *P. expansum* in soils.

Quantification of *P. expansum* on apple fruit at harvest**:** To determine how much inoculum may come into storage on the surface of harvested fruit, 10 arbitrarily selected apple fruits were harvested from each of three trees in four different orchards during fall of 2005. One of the orchards was sampled on two different dates. In addition, 10 apples were collected from each of four different replicate Honeycrisp trees in experimental plots that had received three different summer fungicide regimes. In all cases, fruit were brought to the lab where they were individually washed in 500 ml of sterile distilled water containing 0.01% Tween 20. Apples were individually submersed and swirled in the wash solution for 30 sec to dislodge spores from the surfaces of the fruit. A total of 10 fruit were washed in succession, and the wash water was then filtered. The filters were washed to resuspend the spores, and the suspension was plated onto a selective agar medium that favored growth of *Penicillium* species. Plates were incubated at 25 °C for 7 days, after which all visible colonies on the plates were counted. Varying numbers of arbitrarily selected colonies from each plate were sub-cultured onto a different medium to allow identification of the *Penicillium* colonies down to species. Results were used to calculate numbers of all *Penicillium* species per fruit and numbers of *P. expansum* per fruit. The potential spore load for full field bins was calculated assuming that a field bin would hold approximately 2000 fruit.

The number of *P. expansum* spores recovered ranged from a low of about nine to a high of 28 in the five samples taken from sprayed orchards (Orchards A-D, Table 2). In orchard A where fruit was collected from the same block of trees on both 21 September and again on 17 October, the significantly reduced population detected in the second sampling was probably attributable to the week of heavy rain that immediately preceded the second sample date. (Empire fruit were still available in this orchard on 17 October because the orchard was not harvested due to hail damage that occurred in early summer.)

The number of *P. expansum* spores detected on Honeycrisp fruit in our fungicide trial was greatly affected by the fungicide treatments (Table 3). Fruit from control trees that received their last fungicide spray (Topsin M 11 oz/A+ Ziram Granuflo 4 lb/A) on 19 July had more than twice as many *P. expansum* spores as fruit that were sprayed with Pristine fungicide (4.8 oz/100 gal) the day prior to harvest. Trees treated with Topsin M 4 oz/100 gal plus Captan 80WDG 10 oz/100 gal on the day prior to harvest had only one-sixth as many *P. expansum* spores as control trees (Table 3). While Pristine fungicide is very effective for controlling decays in apple fruit, it may not kill spores on contact the way Captan probably does. *P. expansum* accounted for nearly 60% of all *Penicillium* spores on apples from control trees but only 21 and 35% of the *Penicillium* spores on fruit from the Topsin M/Captan and Pristine treatments, respectively. This suggests that the fungicides are more effective against *P. expansum* than against other

unidentified species of *Penicillium* that are also common on apple fruit.

Based on our limited sample in 2005, the numbers of spores that might be brought into storage on fruit surfaces is dwarfed by the inoculum previously measured on field bins.

Although additional sampling should be done in other years and locations, the accumulated evidence from measuring *P. expansum* populations on field bins, in orchard soils, and on apple fruit at harvest suggests that badly contaminated field bins are by far the most important potential source of inoculum for *P. expansum* under conditions prevalent in New York State. In the absence of effective fungicides, sanitizing contaminated field bins should reduce losses to blue mold decay in storages where decay has gradually increased from year to year. Where storage operators choose to use one of the new fungicides (pyrimethanil or fludioxonil) to control *P. expansum*, bin sanitation should still be used reduce selection pressure for fungicide-resistant isolates, thereby extending the useful life of these new fungicides. It may not be cost effective to sanitize all bins every year, but badly contaminated bins (i.e., those showing visible blue stains from fruit that had blue mold decay) should always be sanitized before they are returned to the orchard for refilling.

Table 3. Preliminary results from washing apple fruit collected in Hudson Valley orchards to determine populations of *P. expansum* present on fruit surfaces at harvest.

Or-chard	Variety/treatment	Sample date	Mean cfu/ apple	No. of sub-cul-tures evaluated	% of total cfu that were *P. expansum*	Estimated *P. expansum* spores/bin of apples 2000
A	Empire	21-Sep-05	52.0	540	28.3	29,467
A	Empire	**17-Oct-05	3.0	90	10.0	600
B	Rome Beauty	21-Oct-05	15.3	315	14.6	4,478
C	Golden Delicious	21-Sep-05	5.3	180	8.9	948
D	Delicious	21-Oct-05	20.7	315	19.7	8,135
HVL-1*	Honeycrisp-control	8-Sep-05	50.0	84	59.5	59,524
HVL-2	Honeycrisp-Topsin/Capt	8-Sep-05	22.5	84	21.4	9,643
HVL-3	Honeycrisp-Pristine	8-Sep-05	36.3	84	34.5	25,030

*Samples from Hudson Valley Lab research plots left unsprayed during summer (HVL-1) or sprayed with Topsin M + Captan (HVL-2) or Pristine (HVL-3) one day prior to sampling.

** Spore numbers were presumably reduced compared to earlier sampling in the same orchard due to 13.5 inches of rainfall that occurred 7-15 October.

Sanitation in Storages and Packinghouses

David A. Rosenberger and Anne L. Rugh

Good sanitation is essential both to reduce potential expenses/losses associated with postharvest decays and to eliminate possibilities that apples will become contaminated with human pathogens. Sanitation procedures and methods must be custom-tailored for each packinghouse, but some general principles are outlined below.

Essential practices for all packing operations:

#1: Chlorinate water dump tanks and flumes on apple packing lines.

A survey of 19 apple packinghouses in the Lake Ontario and Hudson Valley regions during spring of 2005 revealed that some packinghouse operators were not using any sanitizer in water flumes. In the surveyed packinghouses, only 11 of the 25 flumes tested had acceptable levels of chlorine. All of the other 14 flumes had detectable populations of *P. expansum* spores in the water. Five flumes contained more than 5,000 spores/ml, a concentration that frequently results in a high incidence of decay when applied to wounded apples in postharvest fungicide trials. Apples run through these flumes are likely to develop decays on the way to market if any of the apples have stem punctures.

Thirteen of the 25 flumes also contained coliform bacteria, with very high populations (>3,500 cfu/ml) in five flumes. (EPA drinking water standards require <5 coliforms/ml.) The abundance of coliform bacteria was strongly and positively correlated with flume water temperature. Packing-houses that heat flume water to warm apples prior to waxing should be especially careful to maintain effective chlorine concentrations in their flume water. Improved sanitation of packinghouse water flumes is essential both to eliminate inoculum of decay fungi and because of human health concerns.

A more complete discussion about chlorinating water flumes was included in last year's newsletter (see http://www.hort.cornell.edu/watkins/Newsletter2004.pdf.

#2: Remove all decayed fruit from bins as the bins are emptied.

Decayed fruit do not float and therefore must be manually removed from bins after they come out of water dumps. The only alternative is an automated bin-washing system that inverts the bins while washing them with water jets. Decayed fruit left in the bin will harbor millions of spores that can then be carried into the postharvest drench water and packinghouse water flumes when bins are reused the following year. Leaving decayed fruit in empty bins will create tremendous selection pressure for resistance to the new postharvest fungicides. Complete sanitizing of bins that contained decayed fruit is the best option, but removal of decay fruit is essential even where sanitizing bins may not be feasible.

#3: Sanitize storage rooms at the end of each season.

Walls and floors of all storage rooms should be sanitized at the end of each season using either quaternary

ammonium sprays or by applying a foam containing StorOx. Both methods will effectively kill spores and eliminate "storage" odors. Chlorinated water is less effective than quaternary ammonium sanitizers or StorOx foam and is not recommended for cleaning storages.

Recommended practices

#1: Install automated feed pumps to maintain chlorine and pH levels in water flumes, and use filtration to remove particulate matter from recirculating flume water.

The best approach for maintaining consistent chlorine and pH levels in water flumes involves installation of automated feed pumps that continuously monitor chlorine and pH in the water flume and automatically adjust chlorine and pH as needed. Automated systems can be purchased for about $5,000 and require minimal attention and maintenance once they are installed. The advantage of these automated systems is that, because they add chlorine on demand, they can be set to maintain 40-50 ppm free chlorine rather than the 100 ppm free chlorine that is recommended when chlorine is added manually once or twice a day. The lower level of chlorine and the automatic adjustment of pH reduce the likelihood that off gassing will occur due to low pH (i.e., reduces chances of developing a swimming pool odor). It also reduces the likelihood that pH will rise enough to make the chlorine ineffective or that chlorine levels will drop below effective levels.

Hypochlorite, the biologically active molecule in chlorinated water, reacts rapidly with organic matter, so hypochlorite is constantly consumed in flume water that contains organic debris. Centrifugal filters and/or sand filters connected to the water flumes and water dumps can remove organic debris and thereby minimize the need for constant additions of large amounts of chlorine. This is especially critical in presize lines where water is changed relatively infrequently and constant additions of large amounts of chlorine can eventually result in phytotoxic salt levels in the water flumes. However, filtration is recommended even for smaller water dumps. Water that is filtered and chlorinated appears clean and is drinkable even after many bins of fruit have been processed. Fruit that consumers eat with minimal washing should be handled using clean water!

#2: Sanitize floors and other surfaces in the packinghouses periodically during the winter packing season.

Applying quaternary ammonium sanitizers to packinghouse floors just before the work day begins might prove useful for reducing spore populations apple packinghouses during winter when lack of venting can result in the build-up of huge spore populations in packinghouses. Studies conducted in a 10-ft high plastic greenhouse at the Hudson Valley Lab showed that most airborne spores of *P. expansum* settled to the floor within 4-6 hr in still air. A quaternary ammonium sanitizer (Deccosan 315) applied to the concrete floor after a 12-hr settling period eliminated most of the inoculum that had been released into the greenhouse at the start of the experiment. The sanitizer was mixed in water to provide a 200-ppm concentration and was then applied to the floor with a Solo backpack sprayer at a rate of 1 gal of mixed solution per 350 square feet of

floor. This rate of application resulted in even wetting of the untreated concrete surface without puddling of the spray solution. Applying the quaternary ammonium solution to the floor before spores settled was not effective because the solution dried before the spores settled and came into contact with it.

Based on this research, we suggest that packinghouse operators might wish to periodically apply a quaternary ammonium spray to floors and other surface areas within packinghouses during the long winter packing season when packinghouses are rarely vented. (Electronic equipment and motors should not be sprayed because we do not know how repeated exposures to quaternary ammonium solutions might affect these components.) The quaternary ammonium sanitizer needs to be applied in early morning after spores have settled over night and before morning activities are initiated in the packinghouse because spores on the floor will become airborne again as daytime activities are resumed. One concern about spraying floors in early morning is that the wet floors might be slippery for workers, and the amount of time required for the floors to dry might create scheduling problems. This concern could be avoided by applying the quaternary ammonium sanitizer at weekly intervals on a Saturday or Sunday morning when the packing line will not be operating, thereby allowing plenty of time for the floor to dry before workers re-enter the packinghouse.

Cleaning and sanitizing floors under and around packing line equipment can be difficult if there is not enough clearance between the equipment and concrete floors or if the area beneath the packing line is cluttered with support legs and cross-bracing structures. (Do equipment designers get a bonus for every additional leg they put on their packing line equipment??) When planning for new packing lines, it may be advisable to install the line at a height that allows easy access for cleaning beneath the equipment. At the same time, those purchasing packing line equipment should be asking manufacturers for equipment that is mounted on solid round "pods" that can be bolted to the floor, thereby minimizing the number of legs that create barriers to effective sanitation in the packinghouse.

#3: Sanitize bins, especially bins that are badly contaminated, before re-using them.

As reported in previous years, contaminated bins can harbor hundreds of millions of *Penicillium* spores and carry the spores from the end of the storage season into the next harvest season. Bins that contained large numbers of decayed fruit or bins that have visible blue stains due to contact of decays with bin walls should be sanitized by washing with a high-pressure sprayer. When cleaning bins with a high-pressure sprayer, sanitizing can be accomplished by using steaming water (i.e., heat), quaternary ammonium, a chlorine dioxide foam, StorOx applied in a foam, or perhaps by using chlorinated water. Chlorinated water is probably be less effective than the other options because the bin surfaces may not remain wet long enough for the hypochlorite to kill all of the spores. However, the combination of high-pressure washing plus chlorinated water should still eliminate most of the spores because many spores will be washed away by the high-

pressure jets of water even if contact time with the hypochlorite is insufficient for a 100% kill of the spores.

#4: Transition to plastic bins as rapidly as possible.

Plastic bins are easier to sanitize, cause less bruising and fruit injuries where fruit contact the sides of bins, and do not harbor wood-decay fungi that are commonly found in older wooden bins and that may contribute to "storage odors" that sometimes develop when fruit are stored in wood bins. Plastic bins may still need to be cleaned as described above, but thorough cleaning will be much easier than with wooden bins.

Sanitation of plastic bins would be much simpler if the bin manufacturers developed an alternative to the open honeycomb structure on the underside of the bin floor that supplies strength to the bin structure. The open honeycomb structure increases total surface area of the bin dramatically and is difficult to clean. Those making large investments in plastic bins should press the manufacturers to come up with alternative designs that minimize the total surface area that needs to be cleaned each year when bins are sanitized.

<u>Questionable practices</u>

#1: Ozone generators in CA storage rooms have no proven benefits.

Ozone generators are being promoted for apple storage rooms as a means for controlling decays and reducing ethylene levels in apple storage rooms. Ozone generators are commonly used in California lemon storages because ozone limits the ability of spores to form on the surface of fruits that have developed decays caused by *Penicillium* species. (The *Penicillium* species that attach citrus fruits are different from those that attack apples.) Lemons are stored at about 50° F. At that temperature, *Penicillium* can grow rapidly and spores produced by initial decays can spread to other fruit and cause secondary and tertiary cycles of decay. In apples, *P. expansum* grows more slowly due to the colder storage temperature. Generally it does not sporulate under CA conditions, although spores can form quickly after CA rooms are opened. In apples we do not have the secondary cycles of spore production and infection that are common in lemons, and the claimed benefits of ozone for decay control are therefore dubious.

Because ozone generators will not affect internal ethylene production of apples that have not been treated with 1-MCP, the value of "burning off" the atmospheric ethylene in a CA room is also questionable. In the absence of research data showing a clear benefit from ozone in apple CA rooms, growers might better invest in alternative technologies.

#2: Copper-ion generators and other alternatives to chlorination are usually more expensive and/or less effective than chlorination.

Some of the alternatives to chlorinated water may be effective, but they are rarely cost-effective. Always ask vendors for details of scientific studies that document advantages of their systems compared to chlorinated water, and study carefully the costs required to achieve an effective dose of alternatives for the size of flumes used in your own packing operation.

Fungicide Options for Decay Control

David A. Rosenberger

The best option for minimizing blue mold decay in stored fruit involves using clean bins, avoiding drenches after harvest, and storing apples in sanitized storage rooms. This combination of sanitation practices will minimize exposure of fruit to spores of *Penicillium expansum*, the fungus that causes blue mold. *P. expansum* causes the vast majority of postharvest decays in most years.

However, postharvest treatment with diphenylamine (DPA) may be needed to control storage scald and/or carbon dioxide injury with some cultivars. A fungicide should ALWAYS be included in the drench solution when DPA is applied after harvest. Postharvest fungicide treatment may also be desired to control gray mold decay caused by *Botrytis cinerea*, a fungus that may infect fruit calyces in the field and then invades fruit during long-term storage. When fruit are moved into storage without a postharvest treatment, the incidence of blue mold is usually low but the incidence of gray mold is often higher than in fruit that receives a postharvest fungicide treatment. After CA storage, fruit with gray mold are usually firm and light tan with a "baked apple" appearance whereas decays caused by *P. expansum* are soft and watery.

Thiabendazole (trade name: Mertect 340F) and captan are still registered for postharvest treatment of apples. Captan is usually used in combination with Mertect 340F, although Mertect 340F can be used as the sole fungicide in combination with a DPA treatment. In some storages, Mertect 340F is almost worthless because most of the *Penicillium* spores in these packing houses are resistant to Mertect 340F and the resistant spores cycle from year to year on contaminated field bins. Many storage operators report that the combination of Mertect 340F plus captan is more effective than Mertect 340F used alone. In repeated testing where wounded fruit are inoculated just prior to application of fungicides, Captan has always been less effective for protecting fruit than are Penbotec, Scholar, and (in the absence of resistance) Mertect 340F. However, Captan may kill spores that accumulate in drench solutions, thereby decreasing inoculum availability and reducing fruit infection even though it performs poorly in tests where inoculum is applied to fruit just before or after captan treatment. That hypothesis is currently being tested.

Two new fungicides are now fully registered for postharvest treatment of apples in the U.S. Pyrimethanil (trade name: Penbotec) and fludioxonil (trade name: Scholar) are extremely effective for controlling blue mold and gray mold on apples. Both Penbotec and Scholar are fully compatible with DPA and calcium chloride. Both products are very stable and hold up well in postharvest drench solutions. Both products are registered for use in drenches as well as for application in packinghouse line sprays. The line spray application should reduce chances that decays will develop in packed fruit after it enters distribution channels. Packing line applications may be especially valuable if fruit on the packing line are being

exposed to high inoculum levels such as those that occur when bins removed from storage already contain many decayed fruit.

Warning: *Residue tolerances for these new fungicides have not yet been established in many apple-importing countries. Before applying these fungicides to apples destined for export, packinghouse operators should verify that the importing country will accept product treated with the fungicide in question. A database of approved MRLs (maximum residue levels) for various commodities and countries can be found at the following web site:* http://mrldatabase.com.

Packinghouse operators choosing to use these new fungicides should use Penbotec in one year and Scholar the next year so that *Penicillium* spores that recycle on bins will not be repeatedly exposed to the same fungicide year after year. Penbotec and Scholar have different modes of action, and both of them are distinctly different from Mertect 340F. Alternating annually between Penbotec and Scholar should reduce selection pressure for resistance to both of these new fungicide chemistries. Adding Captan to the Penbotec or Scholar in drench solutions might further reduce selection pressure for resistant isolates, but that strategy needs further testing before it can be recommended. Alternation of chemistries for fungicides applied in packinghouse line sprays is of less concern because the treated fruit are moved into the retail supply chain before any surviving infections can sporulate, thereby reducing or eliminating selection for fungicide resistance.

Honeycrisp growers may wish to consider a third new possibility for postharvest decay control. The new fungicide Pristine is NOT registered for postharvest treatments, but there is some evidence that field sprays applied several days prior to harvest can reduce the incidence of decays that develop after harvest. Pristine not only controls *P. expansum* and *B. cinerea*, it is also very effective against black rot, white rot, and bitter rot. All three of those diseases can appear after harvest as a result of infections that were initiated in the field. We do not yet know if a single application of Pristine during the week prior to harvest will be sufficient to suppress postharvest appearance of these summer fruit rots, or whether multiple preharvest applications (perhaps at 30 and 7 days before harvest) will be required for complete control of these diseases on Honeycrisp. Effectiveness of field sprays will definitely depend on spray coverage, and field sprays are unlikely to provide protection against blue mold and gray mold infections that are initiated at stem punctures incurred during harvest. Nevertheless, considering the high value of Honeycrisp apples, at least one preharvest application of Pristine might be justified. If Honeycrisp apples are to be stored more than a month or two, the preharvest spray of Pristine should be followed with a postharvest drench of Penbotec or Scholar. The combination of Pristine before harvest and Penbotec or Scholar after harvest should eliminate most of the postharvest decay in Honeycrisp except in cases where chilling injury causes tissue damage. After investing in expensive new fungicides to protect fruit from postharvest decays, special care should be taken to store Honeycrisp at temperatures that will not cause chilling injury.

Effects of 1-MCP on Incidence and Severity of Decay in Stored Apples

David A. Rosenberger, F.W. Meyer and Anne L. Rugh

Multiple studies conducted in NY and in Ontario have provided inconsistent answers to questions about whether treatment with 1-MCP makes apples more susceptible or more resistant to postharvest decays. Studies in NY during the 2003-04 storage season suggested that wounded and inoculated fruit treated with 1-MCP and held in cold air storage decayed more rapidly than similar fruit that had not been treated with 1-MCP. However, there was no effect of 1-MCP treatment when fruit were held in CA storage. Results of several additional trials conducted during the 2004-05 storage season are detailed below.

Trial 1: In a very large trial (96 treatments) conducted at the Hudson Valley Lab, we used wounded Empire apples to investigate the effects of three inoculum concentrations, four different time intervals between wounding and inoculation (to determine if wounds lose susceptibility to decay if inoculum does not reach the wound until 24-72 hr after wounding), and timing of 1-MCP application (to determine if applying 1-MCP before inoculation has a different impact than applying 1-MCP after inoculation). All treatments were stored in cold air storage. At low inoculum levels (500 spores/ml), we found that after 60 days and also after 102 days of cold air storage, incidence of decay was much higher in fruit treated with 1-MCP than in non-treated fruit regardless of whether inoculation occurred before or 1-MCP was applied. At higher inoculum levels (2,500 or 10,000 spores/mil) differences among treatments were less distinct. None of the fruit in this trial were treated with postharvest fungicides.

Trial 2: Another trial was conducted to determine if there were any discernable interactions between postharvest fungicides and 1-MCP. Apples were harvested from 9-yr-old Empire trees on M.9 rootstock on 4 Oct. The next day, half of the apples were wounded on a single hemisphere using a large cork fitted with three finishing nails spaced about three-eighth in. apart in a triangular pattern. Wounded apples were dip-inoculated for 30 sec. in a suspension of $1x10^4$ spores/ml of *P. expansum.* The inoculum consisted of a 1:1 mixture of benzimidazole-sensitive and benzimidazole-resistant conidia. Baskets of fruit were treated by submersion for 30 sec in 15 gal of either water or fungicide suspensions contained in 30-gal plastic garbage cans. Each fungicide treatment was replicated four times. Fungicides were similarly applied to equal numbers of non-wounded, non-inoculated fruit that were used for firmness evaluations at the end of the experiment. All of the fruit were laid out on spring cushion trays, packed into fiberboard boxes, and moved to a 40°F cold room on the afternoon of 5 Oct. On 6 Oct, half of the wounded and inoculated apples and half of the non-wounded, non-inoculated apples from each treatment (i.e., 20 fruit per replicate) were exposed to 1 ppm 1-MCP. All fruit were then moved to a 36°F

cold room where they were held until 3 Jan. Inoculated fruit were observed for decay development after 59 and 90 days of cold storage and again after a 9-day shelf-life test. An apple was considered decayed if infections occurred at any of the three wound sites. On 3 Jan, the non-wounded, non-inoculated apples were moved into the lab to warm overnight. Firmness of these fruit was determined on 4 Jan using 20 fruit per replicate and testing opposite sides of each fruit.

As expected, Mertect failed to control decay because the inoculum included resistant isolates. After 59 days in cold storage, the incidence of fruit decay in control and Mertect treatments was 88 and 96 percent, respectively, for fruit treated with 1-MCP. The corresponding numbers for fruit not treated with 1-MCP were 70 and 65 percent. None of the other treatments had more than 1.3% of fruit with decay. Decay in the control and Mertect treatments continued to increase between 59 and 90 days after inoculation, but the incidence of decay in other treatments remained very low through 90 days of cold storage (Table 1). At the end of the shelf-life test, Penbotec was the only fungicide that continued to provide nearly complete decay control regardless of whether or not fruit had been treated with 1-MCP. Scholar 200SC and BAS 516F provided control comparable to Penbotec on fruit without 1-MCP treatment, but were significantly less effective than Penbotec on fruit that received 1-MCP treatment. None of the fungicide treatments had any effect on fruit firmness. Fruit treated with 1-MCP were significantly firmer than those not receiving 1-MCP treatment. Effects of 1-MCP on decay development were presumably attributable to its effects on postharvest fruit physiology (delaying senescence) rather than to direct interference of 1-MCP with growth of *Penicillium* spores.

Conclusions: Treatment with 1-MCP may cause a slight increase in decay susceptibility for wounded fruit that are not held in CA storage and that do not receive postharvest fungicide treatments. In long-term CA storage, 1-MCP may actually help to reduce decay by delaying fruit senescence. Observations of poly-bagged fruit in grocery stores have shown that the incidence of decay has been much lower since 1-MCP was introduced than it was in the three years prior to that. There is no way to tell whether the reduction of decay in bagged fruit in grocery stores is attributable to effects of 1-MCP, or whether it has been caused by other factors such as improved attention to sanitation or differences among the growing seasons. However, it seems reasonable to assume that 1-MCP is at least partially responsible for the reduction in decay at the retail level because fruit treated with 1-MCP is arriving in stores in better condition.

Table 1. Effects of fungicide and 1-MCP treatments on fruit firmness and on development of blue mold decay in wounded and inoculated Empire apples that were stored in cold air for 90 days.

Material and rate of formulated product per 100 gal drench solution	% fruit with blue mold after: 90 days at 36°F		90 days at 36°F plus 9-day shelf-life test at 66°F		Mean fruit firmness (lb) after 90 days storage at 36°F	
	With 1-MCP	No 1-MCP	With 1-MCP	No 1-MCP	With 1-MCP	No 1-MCP
Control	100*b[*]	94 b	100 c	99 c	11.1 a	9.1 a
Mertect 340F 16 fl oz	100*b	86 b	100 c	100 c	11.3 a	9 a
Scholar 50W 8 oz	0 a	1 a	15 b	14 b	11.3 a	9.3 a
Scholar 230 SC 19.2 fl oz	0 a	0 a	16*b	1 a	11.2 a	9.3 a
PenBoTec 40% 16 fl oz	0 a	0 a	0 a	1 a	11.3 a	9.5 a
[**]BAS 516F 38%WG 33.7 oz	0 a	1 a	13 b	7 ab	10.9 a	9.4 a
Grand means: effects of 1-MCP	33 B	30 A	41 A	37 A	11.2 B	9.3 A

[*]Means within columns followed by the same small letter are not significantly different ($P \leq 0.05$) as determined using Fisher's Protected LSD to separate means from the two-way analyses. Means followed by asterisks indicate significant differences between simple means for fruit with/without 1-MCP treatment.

[**]Experimental product not registered for postharvest use.

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