2001 CORNELL FRUIT HANDLING AND STORAGE NEWSLETTER

Items of Interest for Storage Operators
in
New York and Beyond

Chris B. Watkins
Department of Horticulture
Cornell University
Ithaca, NY 14853
Voice: 607-255-1784; Fax: 607-255-0599
E-mail: cbw3@cornell.edu
and
David A. Rosenberger
Cornell's Hudson Valley Laboratory
PO Box 727, Highland, NY 12528
Voice: 845--691-7231; Fax: 845-691-2719
E-mail: dar22@cornell.edu

You may now locate the CA Newsletter in electronic format at:
http://www.hort.cornell.edu/extension/commercial/fruit/index.html

Use of 1-MCP to maintain apple fruit quality

A revolution may be occurring in our ability to control ripening of apple fruit! 1-Methylcyclopropene (1-MCP) is an exciting new compound that has tremendous potential to improve our ability to maintain quality of harvested apples and thereby provide better fruit for the consumer. 1-MCP is likely to receive federal registration in 2002, and therefore it will soon be available to the New York industry.

We want to ensure that critical information required for successful utilization of 1-MCP by the New York industry is available. Our program has two initial objectives:

1. Defining variety responses to 1-MCP in air and CA storage, and the effects of different handling procedures; and
2. Evaluating MCP under commercial conditions.

Effects of delays between harvest and application of 1-MCP

Under commercial conditions it will be necessary to accumulate fruit before treatment with 1-MCP. To test the effects of delay on responses of fruit to 1-MCP, we used McIntosh, Cortland, Empire, Delicious, and Jonagold apples harvested from the Cornell Research Orchard at Ithaca. Fruit were harvested during the optimum harvest period for CA storage for each variety (Table 1).

One lot of fruit was treated overnight with 1ppm 1-MCP (18 hours), and then placed into cold storage. The remaining fruit were placed into cold storage on the day of harvest and then either untreated, or treated with 1ppm 1-MCP on day 1, 2, 3, 4, 6 or 8 after harvest for 24 hours**.** Two replicates of 40 fruit were used for each treatment.

Fruit were stored at 32^{o}F in air for 2 and 4 months, or in CA for 4 and 8 months. CA was applied on d 10 and final atmospheres were obtained within 2-3 days. Atmospheres used were 2% carbon dioxide and 2% oxygen at 33^{o}F for all varieties except McIntosh and Empire, which were stored at 36^{o}F. Carbon dioxide concentrations were increased to 5% after one month in the case of McIntosh. At each storage removal, flesh firmness was assessed after 1 and 7 days at 68^{o}F.

Results

The data for both 1 and 7 days at 68^{o}F after removal from storage has been combined for each data set, as even where differences were detectable they were not consistent. Typically, 1-MCP-treated fruit did not soften during the shelf-life period. A full presentation of the experiments is available in the Proceedings of the Storage Workshop 2001, NRAES-153, and results from only selected varieties are shown here.

Table 1. Harvest date for the varieties used in the 1-MCP trials

Variety	Harvest date (2000)
McIntosh	September 18
Cortland	September 25
Empire	September 28
Delicious	October 9
Jonagold	October 6

MCINTOSH:(Fig.1) 1-MCP treatment resulted in firmer fruit, averaging 2.1lb and 1.7lb greater than untreated fruit after 2 and 4 months air storage, respectively. Therefore, while 1-MCP delays softening in air storage, it is not a substitute for long-term CA storage. In CA, the differences averaged 2.1lb and 2.5lb for 4 and 8 months, respectively. 1-MCP treatment became less effective after 6 or 4 days delay before treatment, however, in fruit stored in CA for 4 and 8 months, respectively.

CORTLAND (Fig. 1): In air storage for 2 or 4 months, firmness of 1-MCP-treated fruit averaged 14.2lb and 13.0lb after 2 and 4 months of storage respectively, compared with 11.7lb and 11.1lb in untreated fruit at the same time. After 2 and 4 months, fruit treated with 1-MCP after 4 and 2 days, respectively, were softer than fruit treated sooner after harvest.

1-MCP treated fruit stored in CA were 14.0lb and 14.2lb after 4 and 8 months of storage, respectively. In contrast, untreated fruit at these times were 11.3lb and 10.7lb. Fruit treated with 1-MCP after 4 and 3 days, respectively, were generally softer than fruit treated sooner after harvest.

Thus 1-MCP will maintain firmness of air-stored 'Cortland' at least up to 2 months, and in CA-stored fruit for 8 months. Firmness of air-stored 1-MCP-treated fruit was better than that of untreated fruit, but effects of delaying application of 1-MCP became more pronounced with longer storage periods or longer treatment delays. Fruit destined for air storage should be treated with 1-MCP within 4 days of harvest. CA-stored fruit can be treated up to 8 days from harvest.

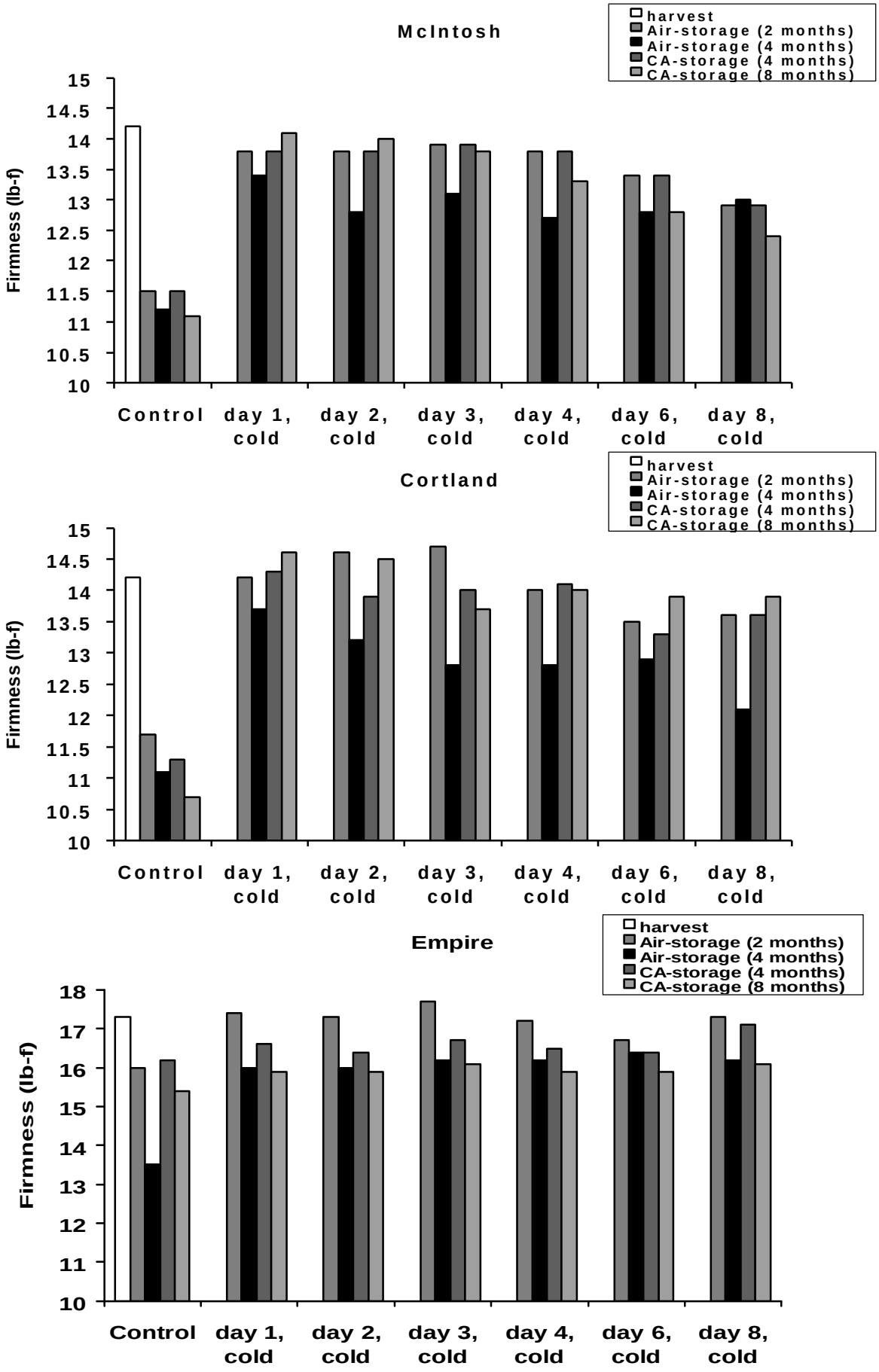
EMPIRE:(Fig.1): Firmness of 1-MCP-treated fruit was 1.3lb and 2.7lb greater than untreated fruit after 2 and 4 months of air storage. Firmness benefits of 0.5lb and 0.6lb for 1-MCP treatment after 4 and 8 months of CA storage were small because untreated fruit in CA softened relatively slowly. There was no consistent effect of treatment time.

Thus Empire fruit respond extremely well to 1-MCP treatment if harvested at the pre-climacteric stage. 1-MCP-treated fruit, with little ethylene production at harvest, were as firm as at harvest after 2 months of air storage, and after 4 months of air storage were similar to those fruit stored in standard CA. Small, but significant advantages to 1-MCP use were apparent after 4 months of air storage, and 8 months of CA storage. No consistent effect of treatment day was detected.

Conclusions

1. While all varieties tested in these experiments responded to 1-MCP as assessed by maintenance of firmness, variety affected the magnitude of fruit response in both air and CA storage.
2. Timing of application after harvest affected 1-MCP effectiveness in Cortland and McIntosh. A preliminary recommendation from this study is that storage operators should aim for a 4-day loading period for these varieties. Rapid CA procedures should continue to be used for all varieties.
3. 1-MCP may substitute for CA storage but often the effects of both technologies are additive. Variability in fruit response to 1-MCP across seasons and harvests may occur and therefore the "insurance" of CA storage is recommended. However, the data clearly indicate that 1-MCP markedly improves quality of fruit

Fig. 1 Flesh firmness of McIntosh, Cortland and Empire apples treated after 1, 2, 3, 4, 6 or 8 days after harvest and stored in air for 2 and 4 months or CA for 4 and 8 months.



stored for at least two months in air, and therefore has the potential to improve the quality of air-stored fruit presented to the consumer in December. 1-MCP treatment effects on quality of air-stored fruit may be influenced more by harvest date and delays before application than CA-stored fruit.

The Grow New York Project

Lack of registration for 1-MCP means that any tested fruit must be destroyed. Therefore testing of the compound under commercial storage volumes of fruit is prohibitively expensive. However, in 2000, we carried out semi-commercial trials with 1-MCP under the auspices of the State of New York, Grow New York Grant Program. The aims of this program include funding of projects that involve application of new technologies with the potential for near term commercial application. In conjunction with matching funding from the New York Apple Association and Cornell University, the Grow New York Grant Program has allowed us to develop a unique approach to fast track gaining of valuable commercial information.

The project was carried out at 4 storage sites in New York State, with most emphasis being on Western New York because of its focus on long-term CA storage. Air storage regimens were included to ensure that information obtained in these trials would also be applicable to smaller volume operators who are less focused on CA storage. The cooperators were:

1. Chazy Orchards, Champlain Valley
2. Lake Ontario Fruit, Inc., Orleans County
3. Fowler Brothers Inc., Wayne County
4. K.M. Davies, Wayne County

At each site, fruit were sampled off trucks arriving at the storage facility, or in the case of the Champlain, collected from blocks being harvested on that day. Depending on the storage, 3 to 6 individual fruit orchards or orchard blocks typical of the fruit within an orchard were used. The varieties used were typical of those being harvested commercially during the experimental period. Each sample consisted of 250 apples. Fruit maturity/quality was assessed immediately on 10 fruit, using firmness and starch, and at Lake Ontario, internal ethylene readings were also taken. Of the remaining fruit, 160 were designated for the CA storage, and 80 for regular storage.

The trials were designed to determine if it would be necessary to treat fruit warm on the day of harvest, or if fruit could accumulate while storage rooms were filled before treatment, as would occur under commercial conditions.

The basic protocols for treatment were as follows.

All 1-MCP concentrations were 1ppm and applied in sealed plastic containers either warm or cold for a minimum of 16 hours. There were four comparisons:

1. Warm fruit, no treatment on the day of harvest, and then coolstored.
2. Warm fruit, 1-MCP treated on the day of harvest, and then coolstored.
3. Cooled fruit, coolstored on the day of harvest, and no treatment applied.
4. Cooled fruit, coolstored on the day of harvest, and 1-MCP treated cold according to the timing of the CA storage sealing in the facility used.

For CA storage, 80 were designated for warm treatment. For each 80 fruit sample, 40 were treated with 1-MCP, the others serving as untreated controls. The warm 1-MCP treatment consisted of treating all orchard samples at the end of the day in airtight containers. The remaining 80 apples for the CA treatment were placed in cold storage immediately after arriving at the storage facility. They remained in cold storage until all samples were treated at the same time one-day prior to closing the CA room.

For air storage, 20 fruit were used for warm 1-MCP treatment and 20 as untreated controls. Fruit were treated at the end of the day, held overnight at ambient temperature and put in air storage the next day. For 1-MCP treatment of cold samples, fruit were collected as described above on a daily basis and placed in regular air storage. They remained in cold storage until all samples were treated at the same time one-day prior to closing the CA room, but were kept in air storage.

After treatment, control and 1-MCP-treated fruit were stored in air for 4 months, or in CA until each room was opened for marketing.

Results

Champlain

Only McIntosh apples were evaluated in the Champlain. The McIntosh types were predominantly old strains on seedling rootstocks, or Rogers on seedling or 111, and to a lesser extent Spur on 111 and RedMax on M26. Six CA storage rooms were used. Air stored fruit were assessed after 4 months, whereas CA-stored fruit were assessed after 2 to 8 months, depending on the harvest dates (Table 2). Harvest ranged from September 18 to October 6, fruit from the later harvests being predominantly ReTain-treated.

The results of storing fruit for four months in air are shown in Table 3. Data for evaluation day, i.e. day 1 versus day 7 of shelf life period, were often similar, and therefore were combined for ease of presentation. However, in one storage room, fruit treated warm with 1-MCP did not soften during the shelf-life period, while all other fruit did.

Overall, the firmness of air-stored McIntosh was maintained about 0.9 to1.4lb greater if fruit were treated warm with 1-MCP on the day of harvest. The only exception occurred in the late harvested fruit in room 6. Fruit from the earliest harvest showed the greatest response to 1-MCP treatment. Treatment of cooled fruit with 1-MCP generally did not slow softening, except in the first two harvests. Greater differences may have been detectable earlier in air storage.

CA-stored fruit responded dramatically to 1-MCP (Table 4). These responses were consistent even when fruit were kept in air cold storage for a month after removal from CA storage. Overall, fruit treated warm with 1-MCP were about 3lb firmer than the untreated control fruit. The benefit of 1-MCP on firmness of cold-treated fruit was approximately 50% of that of the warm-treated fruit, although fruit still averaged 14.2lb. The maintenance of firmness in 1-MCP-treated fruit was consistently greater with earlier harvest date, even though these fruit were stored for the longer periods. Effects of harvest date within a storage lot of fruit were sometimes significant, but no consistent pattern was detectable. This indicates that time after harvest before treatment was not important, and detected differences probably resulted from effects of orchard block on fruit storability.

Table 2: Flesh firmness and starch indices of McIntosh fruit in orchard blocks at harvest, and CA storage periods, for the Champlain 1-MCP experiments.

Room number	Harvest dates (2000)	Firmness (lb)	Starch (1-8)	CA room sealed (2000)	CA room opened (approx. months)
1	9/13 - 9/17	18.0	4.0	9/18	5/14/01 (8)
2	9/19 – 9/20	17.9	5.4	9/21	4/16/01 (7)
3	9/21 – 9/22	17.4	4.7	9/23	3/1/01 (6)
4*	9/24 – 9/26	17.6	4.6	9/27	2/1/01 (5)
5*	9/27 – 9/30	17.2	4.5	10/1	1/10/01 (3)
6*	10/1 – 10/5	16.4	5.5	10/6	12/12/00 (2)

*mostly ReTain-treated fruit

Table 3: Firmness of Champlain-grown McIntosh after removal from air storage after 4 months. Fruit were evaluated after 1 and 7 days at room temperature. The data for all harvest dates and for both shelf life periods have been combined.

Room number	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
1	9/13 - 9/17	11.2	12.6	11.1	11.8
2	9/19 – 9/20	10.6	11.6	10.4	10.9
3	9/21 – 9/22	10.2	11.2	10.2	10.2
4	9/24 – 9/26	10.5	11.4	10.5	10.6
5	9/27 – 9/30	10.7	11.6	10.5	10.4
6	10/1 – 10/5	10.7	10.9	10.7	10.5
Grand mean		*10.7*	*11.6*	*10.6*	*10.7*

Table 4: Firmness (lb) of Champlain McIntosh after removal from CA storage after various periods with and without an additional 1 month in air storage. Fruit were evaluated after 1 and 7 days at room temperature. The data for all harvest dates and for both shelf life periods have been combined.

CA

Room Number	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
1	9/13 - 9/17	12.2	15.9	12.1	14.1
2	9/19 – 9/20	13.4	16.4	13.5	15.7
3	9/21 – 9/22	13.3	16.1	13.3	14.3
4	9/24 – 9/26	12.5	15.7	12.8	14.2
5	9/27 – 9/30	12.6	15.8	12.9	14.4
6	10/1 – 10/5	11.7	13.9	12.0	12.2
Grand mean		*12.6*	*15.6*	*12.8*	*14.2*

CA plus 1 month in air

Room number	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
1	9/13 - 9/17	12.4	15.6	12.4	14.3
2	9/19 – 9/20	12.6	15.6	12.9	14.5
3	9/21 – 9/22	13.2	15.9	13.1	14.1
4	9/24 – 9/26	12.3	15.7	12.7	14.2
5	9/27 – 9/30	12.4	15.4	13.0	14.1
6	10/1 – 10/5	10.9	12.8	11.1	11.0
Grand mean		*12.3*	*15.2*	*12.5*	*13.7*

Western New York

Six CA rooms were used in the storage chosen to represent results from Western New York (Table 5).

In air storage, the responses of both Marshall and standard McIntosh strains (Table 6) were similar to those shown for Champlain-grown fruit. The effect of 1-MCP on firmness of the other varieties was much greater, however, especially for Empire. Cortland and Delicious also responded well, although the untreated control fruit of Delicious maintained good firmness. In all cases, the effect of warm treatment was much greater than that of cold treatment.

Under CA storage conditions, all varieties responded well to 1-MCP treatment (Table 7). Even with an additional month in air storage after the CA rooms were opened, Empire apples exceeded minimum export firmness standards.

The effects of treating cold compared with warm fruit were less evident for Cortland, the second Empire harvest, and Delicious, than for the other varieties.

The effects of harvest date within any storage room were not consistent, suggesting that fruit could be accumulated over at least several days before treatment with 1-MCP and closing of these rooms for application of CA.

Table 5: Flesh firmness and starch indices of fruit varieties at harvest, and CA storage periods, for the Western New York 1-MCP experiments.

Variety	Harvest dates (2000)	Internal ethylene (ppm)	Firmness (lb)	Starch (1-8)	CA room sealed (2000)	CA room opened (approx. months)
McIntosh (Marshall)	9/12 - 9/14	110	15.4	6.4	9/17	2/20/01 (5)
McIntosh (standard)	9/18 – 9/21	52	15.2	6.1	9/22	1/22/01 (4)
Cortland	9/18 – 9/21	1	16.0	2.3	9/22	1/22/01 (4)
Empire	9/25 – 9/28	3	17.8	4.8	9/30	5/30/01 (8)
Empire	10/2 – 10/5	14	18.0	5.5	10/7	3/18/01 (5)
Delicious	10/9 – 10/12	21	17.4	3.4	10/24	4/3/01 (5)

Table 6: Firmness (lb) of Western New York-grown varieties after removal from air storage after 4 months. Fruit were evaluated after 1 and 7 days at room temperature. The data for all harvest dates and for both shelf life periods have been combined.

Variety	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
McIntosh (Marshall)	9/12 - 9/14	10.1	11.6	10.3	10.3
McIntosh (standard)	9/18 – 9/21	10.4	12.2	10.5	11.2
Cortland	9/18 – 9/21	10.4	13.2	10.4	11.7
Empire	9/25 – 9/28	12.6	15.3	12.5	13.8
Empire	10/2 – 10/5	12.8	15.6	13.1	13.9

Table 7: Firmness of Western New York-grown varieties after removal from CA storage after various periods with and without an additional 1 month in air storage. Fruit were evaluated after 1 and 7 days at room temperature. The data for all harvest dates and for both shelf life periods have been combined.

CA

Variety	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
McIntosh (Marshall)	9/12 - 9/14	10.9	13.4	10.8	12.6
McIntosh (standard)	9/18 – 9/21	11.3	13.5	11.4	12.4
Cortland	9/18 – 9/21	11.0	13.9	11.2	13.4
Empire	9/25 – 9/28	14.6	16.1	14.7	15.3
Empire	10/2 – 10/5	14.7	16.2	14.8	16.0

CA plus 1 month in air

Variety	Harvest dates (2000)	Treatment			
		Warm control	***Warm 1-MCP***	***Cold control***	***Cold 1-MCP***
McIntosh (Marshall)	9/12 - 9/14	10.8	13.1	10.9	12.1
McIntosh (standard)	9/18 – 9/21	11.4	13.6	11.6	12.3
Cortland	9/18 – 9/21	11.3	14.1	11.0	13.2
Empire	9/25 – 9/28	13.2	15.3	13.3	14.1
Empire	10/2 – 10/5	14.3	16.0	14.3	15.4
Delicious	10/9 – 10/12	14.5	16.0	14.5	15.8

Conclusions:

1. 1-MCP a powerful tool to maintain firmness of New York-grown varieties. The residual effect after removal of fruit from CA suggests that 1-MCP will result in improved shelf life, and better quality fruit in the marketplace.
2. 1-MCP may be a useful substitute for CA storage of Cortland, Empire, and Delicious for limited periods in air. Extension of the regular storage period can also be achieved for these varieties.
3. Responses of fruit to 1-MCP was affected by fruit temperature at the time of treatment. It seems unlikely that the delays between harvest and

treatment of fruit with 1-MCP represented a significant factor in fruit responses to 1-MCP as these times were short, and no consistent differences among harvest date were detected. The reasons for the temperature effect are not known, but may indicate that exposure to 1-MCP should be longer if fruit are treated cold.

4. Low ethylene fruit responded better to 1-MCP treatment than did high ethylene fruit, which suggests fruit should be picked early in the harvest window (pre-climacteric) in order to maximize the benefits.

Inoculum Cycling and Control of *Penicillium expansum*

Dave Rosenberger

Huge numbers of *P. expansum* spores can persist on empty apple bins, especially when decayed fruit mummies remain in bins as they leave the packinghouse (Fig. 1). Bin-washing experiments have shown that a single wooden bin can carry more than 2.2 billion spores of *P. expansum*. Plastic bins carry less than 25% of the spore load found on comparable wooden bins, but the contamination level on plastic bins is greater than might be expected based on their comparatively clean appearance. Switching to plastic bins will not of itself resolve the problem of inoculum being carried from year to year on bin surfaces.

Plastic bins may be easier to sanitize than wooden bins, but we have not done the experiments necessary to validate that assumption. Where *P. expansum* leaves a visible blue stain on bin surfaces, removing and/or killing the spores is difficult because the spore mass is very hydrophobic and therefore some spores in the mass may escape contact with sanitizers. The best methods for sanitizing bins have not yet been determined. However, there can be no doubt that improved bin sanitation is essential for reducing inoculum that cycles from year to year on uncleaned bins.

Airborne inoculum in packinghouses can also contribute to inoculum cycling. Airborne spores that land on bins after they are emptied can survive through summer to contaminate the next year's crop. The airborne inoculum in packinghouses may also be a major contributing factor in the high incidence of decay that has been noted in bagged apples in retail stores.

A portable air sampler for agar plates was used to measure concentrations of airborne spores of *P. expansum* in three packinghouses and their associated cold storage rooms at various intervals throughout two packing seasons. Each time that spore trapping was done, agar plates were also exposed to the air for one minute intervals to determine how many spores would be captured by settling of spores from the air.

Airborne inoculum concentrations were very low in autumn but increased rapidly after CA storage rooms were opened in February and March. Spore concentrations in air varied considerably among the packinghouses but exceeded 150 spores per liter of air in every packinghouse on at least one sampling date each year. In both years, inoculum concentrations dropped on the last trapping date in late winter. The last trapping dates occurred after outdoor temperatures had warmed to the point where packinghouses were being vented to bring in outdoor air. It is not known whether venting alone accounted for the reduced spore concentrations on the last packing date or whether there were other contributing factors.

Spore concentrations in cold storage rooms were consistently low and only rarely exceeded five spores

per liter of air despite the fact that these rooms were connected to the packinghouse, had regular forklift traffic and evaporator fans that circulated air constantly. The high spore concentrations detected near the packing lines as compared the low concentrations in storage rooms suggests that most airborne spores are generated when decayed apples reach the packing line. Spore concentrations remained low during the period before CA rooms were opened because relatively few decays were present in stored fruit packed earlier in the packing season.

The numbers of colonies that developed on plates exposed for one minute near water dumps provided a basis for estimating how many spores per minute might fall onto a flat surface given varying levels of airborne spore concentrations. The spore settling rate between February and May during the two years of spore trapping varied from a low of 0.78 to a high of 9.37 spores per square inch per minute (spores/in^2/min). The mean for February to May across all packinghouses over two years was 3.24 spores/in^2/min. These numbers may sound relatively low, but a settling rate of 3.24 spores/in^2/min means that an empty bin with a footprint of 43x48 inches could accumulate nearly 6,700 spores/minute or 400,000 spores per hour. At the highest spore concentrations measured in packinghouse air, a similar bin would collect nearly 1.2 million spores per hour while sitting in the packinghouse. Thus, bins may be contaminated with spores of *P. expansum* not only from decayed apples in the bin, but also from inoculum that settles from the air onto empty bins that are left in the packinghouse after they are emptied.

How *P. expansum* cycles in apple storages: The most important inoculum cycle involves spores from non-sanitized bins that are released into the drench solutions used to apply DPA and fungicides (Fig. 1). Spores are carried by the drench water to apple stems and infect fruit by invading through the stems during CA storage. Rotting fruit in contact with the bin surface generate more inoculum that persists on bins to infect fruit the next time bins are refilled. In the absence of postharvest drenching, some inoculum may be transferred from contaminated bins by direct contact of fruit with the bin surface or by airborne spores that travel from the bin surface to the fruit stems. However, relatively little inoculum finds its way to fruit stems in the absence of postharvest drenching.

A secondary inoculum cycle for *P. expansum* involves dissemination of airborne spores in the packinghouse (Fig. 2). Airborne spores can be carried to empty bins awaiting removal from the packinghouse. The numbers of spores that can be deposited on a bin are significant (up to 1.2 million spores/hr), but decayed fruit that are left in the bins and blue stains on the sides of bins are probably more important factors in bin contamination than the airborne spores.

Airborne spores could be a primary inoculum source for decays that develop in packed fruit. Another source of decays in packed fruit could be stem infections that were initiated during CA storage but that had not yet caused a fruit decay at the time of packing. When stem-end decays appear in apple bags at the retail level, one can safely assume that the infections occurred during CA storage because stems are susceptible to invasion only during CA storage. Spores in the water dumps might also contaminate fruit as they are being packed, but spores in water dumps can be easily controlled by maintaining 100 ppm of sodium hypochlorite in the water.

Recommendations for breaking the inoculum cycle and reducing postharvest decays: The following suggestions for reducing postharvest

decays have been derived from what is known about the life cycle of *P. expansum*, inoculum cycling, and susceptibility of fruit to decay.

1. Whenever possible, avoid wetting fruit after harvest. Postharvest drenching spreads spores of *P. expansum* from bins to wounds and fruit stems where they can initiate decays. Benzimidazole fungicides are no longer effective against most strains of *P. expansum*.
2. Sanitize bins and storage rooms to minimize the amount of inoculum that is carried from one season to the next. At the very minimum, all decayed fruit should be removed from bins before the bins are returned to the field for refilling. Quaternary ammonia sanitizers are very effective for sanitizing storage rooms and reasonably effective for sanitizing storage bins if the bins do not contain dried residues of decayed fruit. Steam cleaning is probably the most effective way to sanitize bins, but steam cleaning may not be cost-effective.
3. A bin washing machine incorporated into the packing line may provide the most cost-effective way of eliminating *P. expansum* inoculum from bins as they are emptied. However, the advantages of a bin washer will be lost if cleaned bins are stored in an environment where they can be recontaminated by spores from the packing line as might occur when empty bins are stored in CA rooms that are connected to the packinghouse.
4. Use sanitation in packinghouses to minimize infections in packed fruit. Packinghouse sanitation should include chlorination of water dumps, prompt removal of cull bins, and, where possible, regular washing of floors and external venting of air from the packinghouse during operational hours. The latter should help to remove airborne spores instead of allowing them to accumulate in the packinghouse throughout the winter season.
5. When renovating or building new packing lines, consider installing a wall to physically separate the water dump and drying rollers from the fruit-packing portion of the line. Most spores in the packinghouse environment probably originate near the water dump and drying rollers, so isolating this portion of the line could significantly reduce spore contamination on packed fruit. Separating the input and output ends of the line is a standard practice in citrus packinghouses where other species of *Penicillium* can cause huge losses in packed fruit.

Controlling losses to *P. expansum* will require significant improvements in sanitation and fruit handling, but those improvements may soon be required anyway as buyers become more concerned about food safety in fresh produce. Improving sanitation now can make the apple industry appear pro-active on food safety issues at the same time that it reduces losses to postharvest decays.

Fig. 1. Decayed fruit mummies left in bins after they are emptied in packinghouses contribute inoculum that is carried over to the next year's crop.

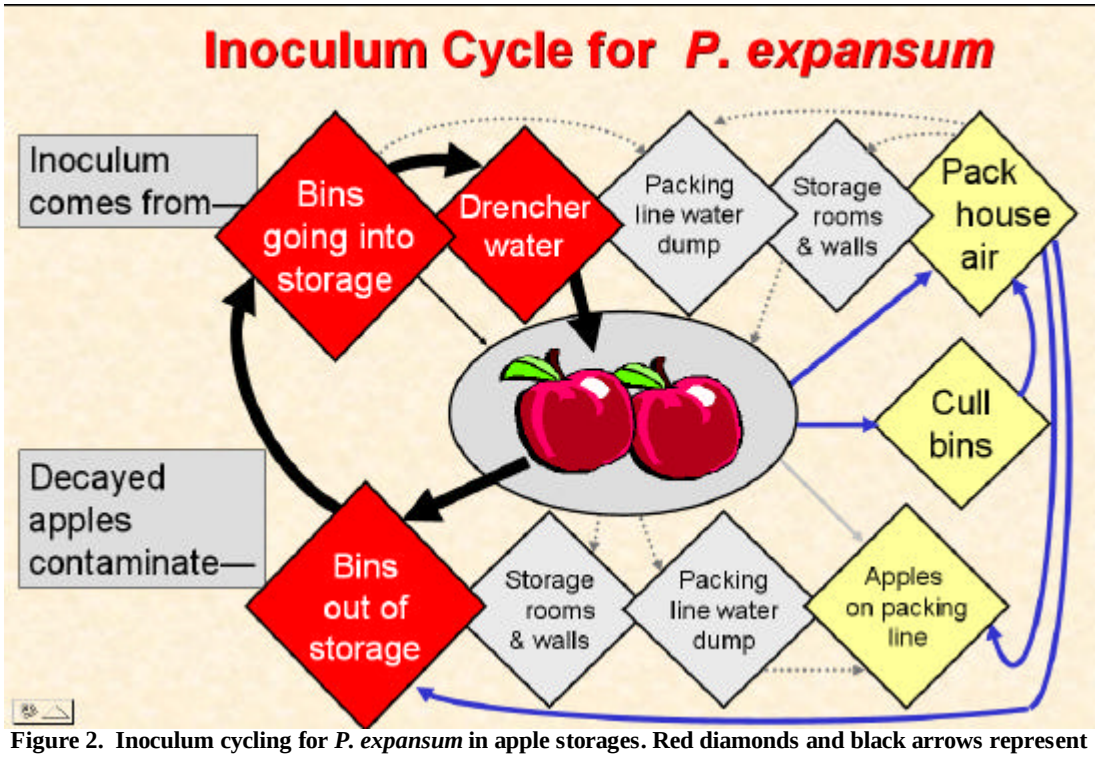


Figure 2. Inoculum cycling for *P. expansum* in apple storages. Red diamonds and black arrows represent the most important components of inoculum cycling. The primary cycle shown by the heavy black arrows involves spores that cycle from bins to drencher water to fruit and back to bins. A secondary cycle (yellow diamonds) involves airborne spores that cycle both to empty bins and to apples on the packing lines. The latter contributes to decays that are present in bagged fruit at retail stores. Contaminated water dumps and storage rooms (gray diamonds) can be significant sources of inoculum, but they are considered less important because they can be eliminated by chlorinating water dumps and by annual cleaning of storage rooms with quaternary ammonia sanitizers.

Apple Tree Nutrition Affects Susceptibility of Empire Fruit to Blue Mold Decay

Dave Rosenberger

Until the 1990's, *Penicillium expansum* was considered primarily a wound pathogen and inoculum was assumed to originate in the orchard each fall. During the late 1990's, however, we discovered that *P. expansum* can invade non-wounded Empire apples through the fruit stem during CA storage (Fig. 1). Invasion through stems does not occur in air storage. Tests conducted in autumn of both 1998 and 1999 using fruit from six different orchards in western NY

showed that differences in boron content of fruit and leaves were significantly correlated with susceptibility to decay. Fruit with higher boron concentrations developed more decay than fruit with lower boron levels when stems were uniformly inoculated with conidia of *P. expansum* immediately after harvest and fruit were then held in long-term CA storage.

Fig. 1. Empire apple with blue mold decay that was initiated when P. expansum invaded the apple through the stem. Note blue sporulation on the side of the stem.

In 2000, replicated plots were established at the Hudson Valley Lab to further test the relationship between boron nutrition and susceptibility to *P. expansum*. Boron treatments were replicated five times in a randomized block design. Each plot contained two Empire trees and two Ace Spur Delicious trees. Plots intended for low boron nutrition received no soil-applied or foliar boron in 2000 although they had received boron treatments in previous years. High-level boron plots received 1 oz of fertilizer-grade boron (14.3% boron formulated as sodium borate) on 6 April 2000 whereas medium-level boron plots received no soil-applied boron. Solubor at 1 lb/100 gallons was sprayed on trees of medium (M) and high (H) boron plots as follows: 14 April (M/H), 19 April (H), 26 April (H); 4 May (H), 12 May (M/H), 30 May (M/H); 8 June (M/H), 19 June (H), 30 June (H), 10 July (H). Thus, plots designed for medium boron levels received four foliar sprays of Solubor whereas trees in high-level plots were sprayed 10 times during the growing season.

Leaf samples were collected from Empire trees in each plot on 3 August 2000 and were sent to Cornell University for mineral analysis. Empire and Delicious fruit were harvested from each plot on 25 September. For each cultivar, 75 Empire fruit and 60 Delicious fruit were inoculated by placing a 10-µl droplet of inoculum on the end of each stem. Each 10-µl droplet contained approximately 500 conidia of a benzimidazole-resistant isolate of *P. expansum*. The inoculated fruit were placed in a CA storage room in western New York on 27 September. The room was sealed on 29 September and was opened on 25 June 2001. Fruit were brought back to the Hudson Valley Lab on 29 June and were held at 34 F until they could be evaluated on 2 July.

The field applications of boron in the Hudson Valley provided foliar boron levels of roughly 24, 30 and 40 ppm for the low, medium, and high boron treatments, respectively. For both cultivars, fruit firmness at harvest was 1.6 lb higher for fruit from the high boron treatment than fruit from the low boron treatment. There were no significant (P=0.05) differences among treatments for either cultivar in starch-iodine index at harvest, so differences in firmness were not due to differences in fruit maturity. Although the high boron fruit were firmer than low boron fruit at harvest, boron levels had no significant affect on fruit firmness as measured when fruit were removed from CA storage in June.

For both Empire and Delicious fruit, the incidence of stem-end decay was greater for fruit from trees that

received boron treatments than for trees that that remained untreated (Table 1). The incidence of decay was more than twice as great in Delicious as in Empire, but this difference probably reflects differences in the way the apples were handled rather than differences in varietal susceptibility. The Empire apples were cooled for 24 hr immediately after inoculation whereas the Delicious fruit were not cooled significantly until approximately 24 hr after inoculations were completed.

This experiment confirmed earlier work showing that *P. expansum* can invade fruit through stems and that boron nutrition affects the susceptibility of fruit to stem invasion during CA storage. In this trial, fruit from trees with foliar boron concentrations of 30 ppm and 40 ppm were significantly more susceptible to stem invasion than fruit from trees that had 24 ppm foliar boron. We do not yet know the optimum boron concentration needed to maximize fruitfulness without making fruit overly susceptible to decay. Nevertheless, there is ample evidence to suggest that foliar boron concentrations over 35 ppm may be inadvisable, at least for Empire fruit, because higher concentrations of boron are unlikely to contribute significantly to tree nutrition. Where boron concentrations are unusually high, special care should be taken to avoid exposing fruit to high concentrations of inoculum from *P. expansum*.

Table 1. Percent stem-inoculated fruit from Hudson Valley field plots that had stem-end decay when evaluated on 2 July 2001 following nine months of CA storage

Fertilizer regime	Boron concentration in Empire leaves (ppm)[1]	Percent stem-inoculated fruit with stem-end decay on 2 July 2001	
		Empire	Delicious
No boron	23.9 a[2]	19.5 a[2]	65.9 a[1]
Mid-level boron	30.5 b	37.6 b	79.7 b
High boron	39.4 c	38.4 b	85.3 b

[1]Based on leaf samples collected from five replicates on 3 August 2000.
[2]Means followed by the same letter are not significantly different (P=0.05).

The 2001 Storage Workshop
Proceedings of the Storage Workshop 2001: Apple Handling and Storage, Cornell University (NRAES-153) are available from NRAES, 152 Riley-Robb Hall, Ithaca, NY 14853 (phone 607 255-7654; Fax 607 254-8770).

Acknowledgements

Work reported here was funded by the New York Apple Research and Development Fund, the Grow New York Program, the New York Apple Association, the NY State IPM Program, and by Smith Lever funds from the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture. The work reported in this newsletter involved many individuals whom the authors thank: Fritz Meyer, Cathy Ahlers, Keri VanCamp, Albert Woelfersheim, and Jackie Nock for technical assistance. The Grow New York trials involved Steve Hoying, Jim Wargo, Kevin Iungerman as well as other helpers. We thank the excellent cooperators at the several packinghouses where trials were undertaken.