MCP: Facts, Speculation, and How Could it Affect the New York Apple Industry?

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This work supported in part by the NY Apple Research & Development Program and the NY Apple Research Association.

> **A revolution may be occurring in our ability to control ripening of apple fruit. MCP is a compound with great potential for the New York industry and may have the impact equivalent to the development of CA storage on the apple industry. It is not a magic bullet, and as with any new product or technology, we have a lot to learn about this compound.**

The dream of every grower, storage operator, and retailer is to have commodities that we put into some type of suspended animation where the fruit do not change from the time of harvest, and then are ripened to reach the consumer in desirable condition. The closest we get to that goal in the modern marketing system is the banana, which is ripened artificially with ethylene after import into the United States and then marketed as it ripens. For the apple industry, however, we are dealing with a perishable product for which "control" of senescence and ripening has been limited to refrigeration and controlled atmosphere (CA) storage in which the oxygen level in the storage atmosphere is lowered while that of carbon dioxide is increased. Cold temperatures and CA storage go part way to slowing down respiration and reducing the production and action of ethylene. Success in applying these technologies to apples is the basis of our industry's reliance on long-term storage of apples. Ethylene, however, continues to be our main "enemy" in preventing us from consistently providing wholesome, fresh apples in the marketplace. None of the technologies available can do more than delay the production and action of ethylene. We are all aware that, despite our best efforts, much fruit arrive in the marketplace in much poorer condition than is ideal. Better control of ethylene production in this fruit would benefit the industry, as firmer and more consistent fruit quality in the marketplace will hopefully encourage growth of apple consumption. Benefits of controlling ethylene may be even greater for the New York industry, with our reliance on varieties such as McIntosh, Cortland, Empire, and Jonagold, which soften readily after harvest.

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Apple CA storage technology has allowed high quality apples to be delivered to consumers for 12 months of the year. Neverthless, fruit condition problems persist.

A revolution may be occurring in our ability to control ripening of apple fruit! Many trade magazines have recently carried articles about a compound known as 1-methylcyclopropene (MCP). It is not difficult to get excited about a compound when one is able to show growers McIntosh apples that have been treated at harvest and after two months at room temperature are still 15 lb! However, in this article we aim to do two things. Firstly, to provide an understanding of how MCP works and its present status in the registration process. Secondly, to provide an update on findings from our research at Ithaca, and try to put this compound in perspective. We hope to convince you that MCP is a compound with great potential for the New York industry, but that it is not a magic bullet. We have already identified a number of limitations, and we have a lot more to learn about MCP before the industry can fully exploit new technologies based on the compound.

What is MCP, and How Does it Work?

MCP is an organic compound, which blocks ethylene receptors and prevents ethylene effects in plant tissues for ex

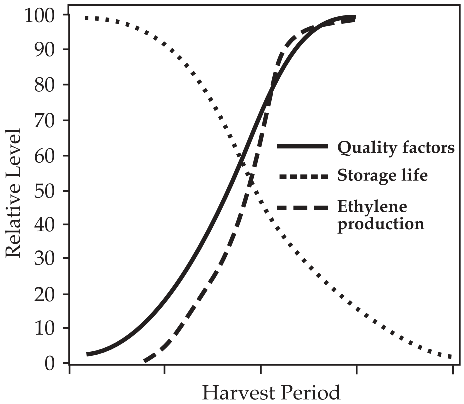

Figure 1. Stylized interpretation of the compromise between increasing fruit quality factors, such as color, sweetness, lower starchiness, aroma and flavor, and decreasing storability of apple fruit. During the time that these factors are moving in opposite directions, ethylene production by the fruit increases markedly in most apple varieties.

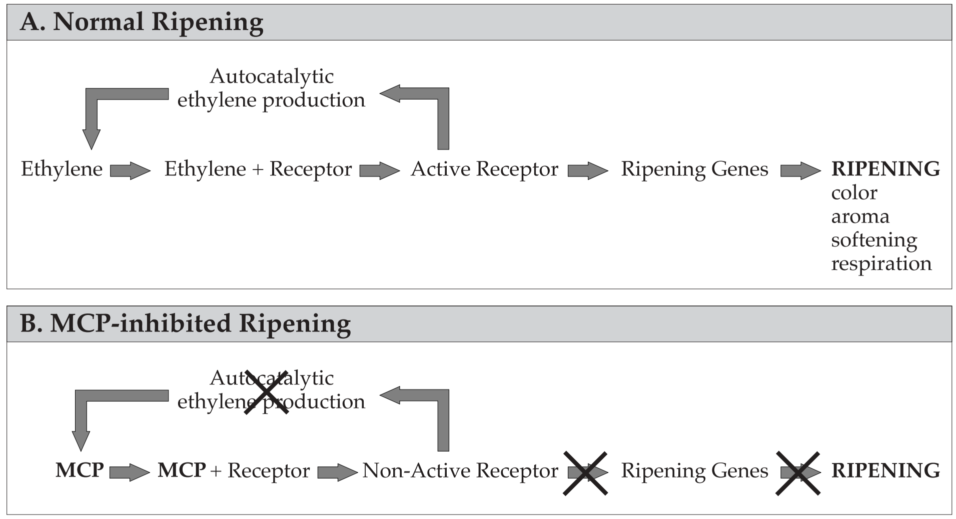

Figure 2. Comparison of normal ripening processes and effects of fruit treated with MCP.

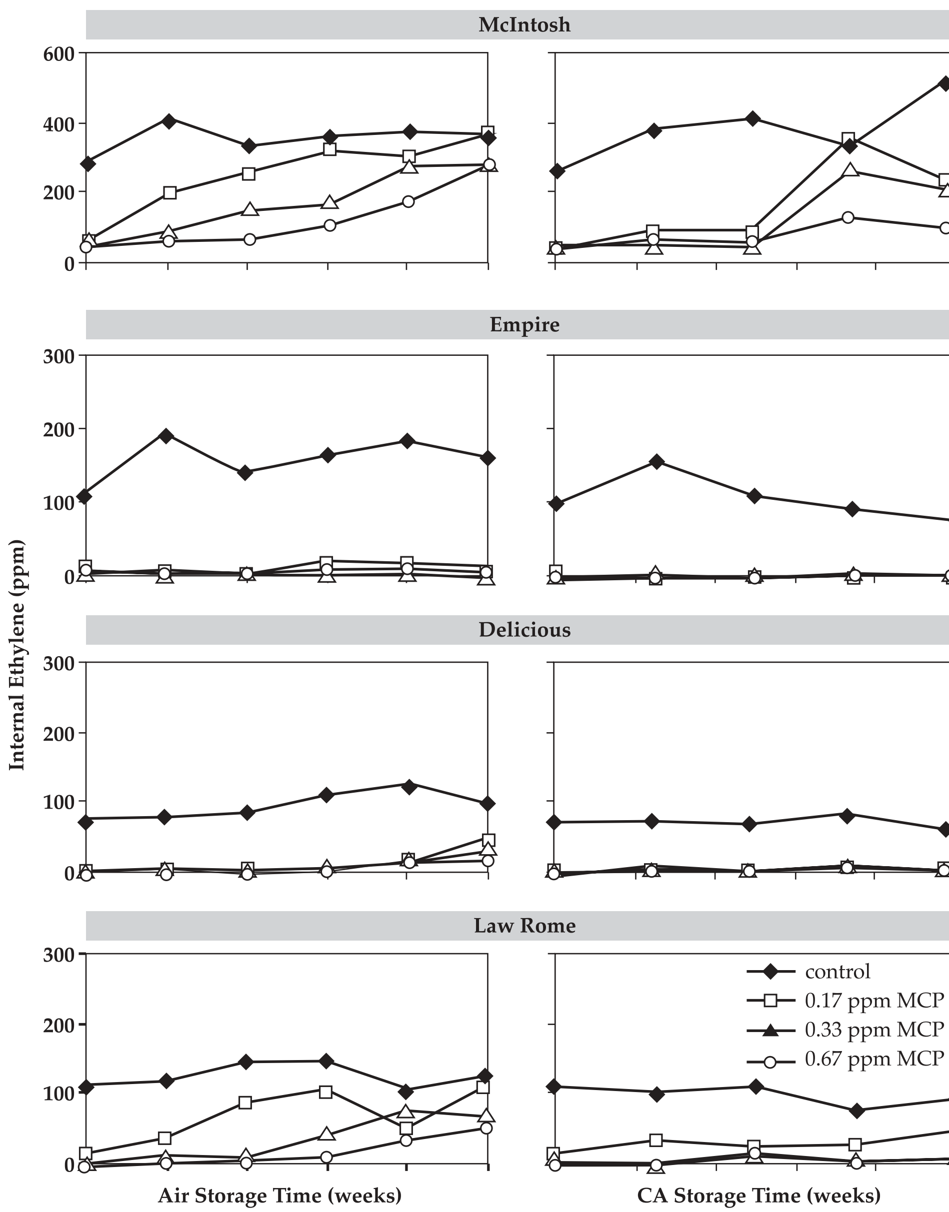

Figure 3. Internal ethylene (ppm) of four apple varieties treated with MCP immediately after harvest and stored in air (left hand column) or CA (right hand column). Fruit were evaluated after removal from storage at the times indicated plus 1 week at 68°F.

tended periods. To understand the action of MCP, we have to first appreciate the role of ethylene in the apple ripening process. Ethylene is a naturally occurring plant growth hormone that is thought to regulate many aspects of fruit ripening. In the apple, an increase in ethylene production generally occurs during the harvest period. Growers often know when this increase has occurred because the build-up of ethylene is often associated with pre-harvest drop, especially in apples such as McIntosh. Compounds such as ReTain™ are used to delay this ethylene increase and reduce this drop. The natural increase in ethylene is associated with increasing quality attributes (e.g. flavor and aroma development) but also decreasing storability (Fig. 1). Harvest of apples is always a compromise therefore, between early harvest where quality of the ripened fruit is lower but storability is high, and later harvest where ripening quality is higher, but potential storage periods are shorter.

Increased ethylene production by fruit involves two interrelated processes. Firstly, ethylene is produced by the action of several biochemical steps involving enzymes. Secondly, however, the ethylene molecules produced by these reactions have to bind to a receptor for rapid ethylene increase (known as autocatalytic ethylene production) to occur (Fig. 2A). The ethylene production is responsible for many ripening-related events such as color change from green to yellow, aroma development, softening, and increased respiration. MCP binds to the receptor and therefore prevents the ethylene increase (Fig. 2B).

TABLE 1

Toxicology data for MCP

- Acute oral toxicity in rats: LD50 > 5,000 mg/kg (not toxic following acute oral exposure).
- Acute dermal toxicity in rabbits: LD50 > 2000 mg/kg (not toxic following acute dermal exposure).,
- Acute inhalation toxicity in rats: LC50 > 165 ppm active ingredient (highest achievable concentration); no adverse effects observed.
- Dermal irritation in rabbits: LD50 > 2,000 mg/kg Non-irritating.
- Eye irritation in rabbits: Slightly irritating.
- Dermal sensitization in guinea pigs: Not a dermal skin sensitizer.
- Ames assay: Non-mutagenic
- Mouse lymphoma assay: Non-mutagenic.
- In vivo mouse bone marrow micronucleus assay: Non-mutagenic.

What is the Registration Status of MCP?

1-MCP is currently formulated as a 0.14 percent powder under the brand name EthylBloc(TM) for the floral market. Acute toxicity, mutagenicity, and product chemistry studies conducted on the end-use formulation indicate a favorable toxicology profile (Table 1). In addition, 1-MCP has a non-toxic mode of action, is applied at extremely low ppb dose levels, and there is no expectation of measurable residues in food commodities. The EPA has classified 1-MCP as a plant growth regulator and structurally related to plant-containing materials and eligible for a reduced data set requirement. EPA registration was granted in flowers in April 1999 and is expected for postharvest use on fruits and vegetables in 2001.

Research Results So Far

We started working with MCP during the 1998 season. MCP was applied to McIntosh, Delicious, Empire, and Law Rome, and fruit were stored either in air (30 weeks) or CA (32 weeks). During storage, fruit samples were removed and evaluated after 1 or 7 days at 68°F. These evaluations included internal ethylene concentrations, firmness, soluble solids, acidity, and occurrence of any storage disorders that developed during the experiment. Only selected results are shown here to illustrate the main findings.

Figure 3 shows the internal ethylene concentrations for each variety stored in air (left hand set of graphs) or CA (right hand set of graphs). Each time point represents fruit removed from storage at that time and then kept at 68°F for a further week. Two things are apparent:

1. MCP controlled ethylene levels to a much greater extent in Delicious and Empire than in McIntosh and Law Rome in both air and CA storage.
2. The effects of MCP were slightly greater under CA than air storage, although this effect was more evident on the day 1 evaluation.

MCP similarly affected softening of the fruit (Fig. 4), with very pronounced reduction of softening in Delicious and Empire apples compared with McIntosh and Law Rome during air storage. MCP in combination with CA storage was very effective in controlling softening, and for McIntosh and Law Rome the fruit from the combined treatment were much firmer than air-stored fruit alone.

A factor of concern to us, however, was that in a population of MCP-treated McIntosh fruit, a mixture of firm and soft fruit existed, even when stored in CA. This is illustrated in Figure 5, which shows individual internal ethylene and firmness data sets in non-treated and MCP-treated fruit stored under CA conditions for 24 weeks and evaluated after a further 7 days at 68°F. The average internal ethylene concentration was 351±107 ppm in untreated fruit. The average internal ethylene concentration was lower (140 ppm) in the MCP-treated fruit, the variation was high being ±95 ppm. Most importantly, this variation was also evident for fruit firmness, being 12.8±1.1lb for untreated fruit, but 15.4±2.2 lbs in MCP-treated fruit.

It appears that for McIntosh, unlike Delicious and Empire, fruit with high ethylene production at harvest cannot be "switched off." This may be a real problem for use of MCP in areas where fruit are harvested with mixed populations of pre-climacteric (not yet producing ethylene) and post-climacteric (producing ethylene) fruit.

In the 1999 season, we tested McIntosh (Rogers strain) apples in two ways. First, we compared the responses of fruit harvested during the harvest window for CA storage on September 15 (IEC = 0.13 ppm, starch index = 4.9 units, firmness = 17.6 lbs) and 15 days later (IEC = 87 ppm, starch index = 6.2 units, firmness = 16.7 lbs). These fruit were treated with MCP concentrations of 0.3, 1.7 and 17 ppm at harvest. The results showed that:

1. In air storage, the 1.7 and 17 ppm MCP concentrations delayed the increase in the IEC of early harvested fruit for up to four months. For the late harvested fruit, the IEC at harvest was reduced only by the 17 ppm MCP treatment. The inhibition of IEC by MCP was reflected in maintenance of firmness of first harvested fruit, but little effect of MCP was found for late harvested fruit.
2. In CA storage, MCP inhibited the increase of IEC in fruit from both harvests, but the effect was more concentration dependent in the late harvested fruit than the early harvested fruit. Again these effects on IEC were largely mirrored by results of fruit softening.

In a second set of experiments, we separated fruit at harvest into fruit that were pre-climacteric (<1 ppm) and fruit that were post-climacteric (>50 ppm), treated them with 0. 3ppm MCP and kept them at 69°F for a week. Firmness of the pre-climacteric fruit was 16.7 lbs in the MCP-treated fruit compared with 13.1lbs in the control fruit, but firmness differences in fruit responses were negligible.

In 1999, we also compared the effects of treating fruit warm (as in the above experiments) with treatment of fruit cooled overnight using Cortland, Delicious, Empire, Gala, Jonagold, McIntosh, and Red Cort varieties. We observed three types of response, which are illustrated in Figure 6. Delicious (which did not respond as positively to MCP as in the previous year) responded less well to MCP when treated cold than warm. Gala effects were independent of treatment temperature, whereas Jonagold responses were better in cold fruit than warm fruit. Cortland, Empire, and McIntosh responses were similar to that of Delicious. Red Cort was similar to Jonagold.

Another important observation from our experiments over two years is that MCP has prevented or reduced the occur

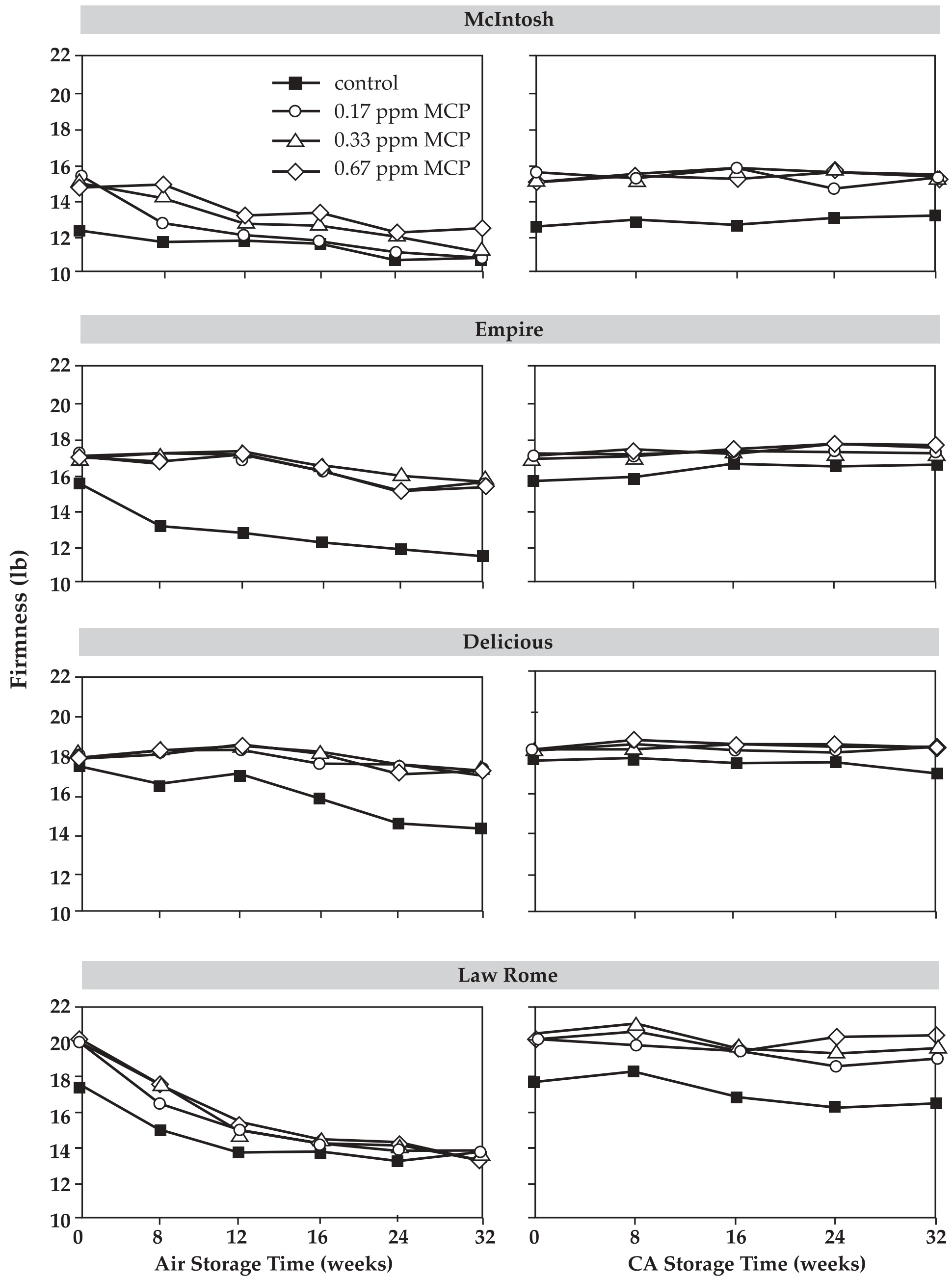

Figure 4. Flesh firmness (lb) of four apple varieties treated with MCP immediately after harvest and stored in air (left hand column) or CA (right hand column). Fruit were evaluated after removal from storage at the times indicated plus 1 week at 68ºF.

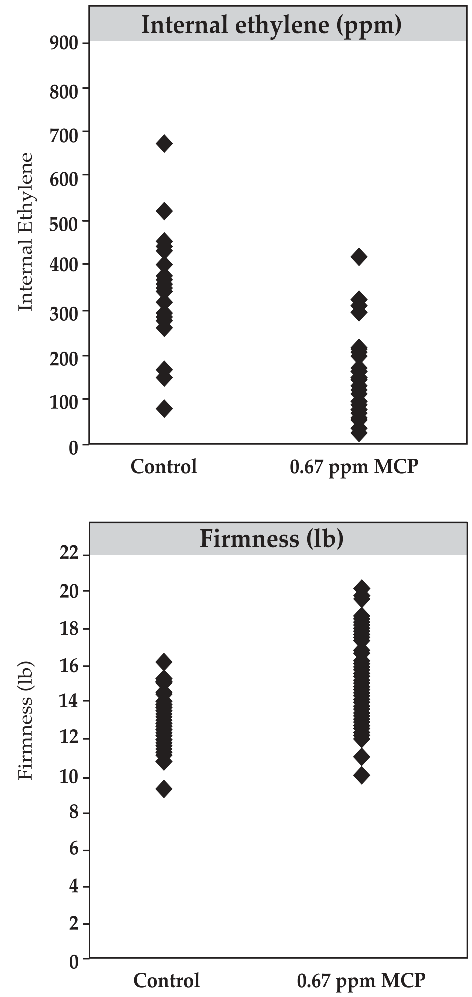

Figure 5. Range of internal ethylene concentrations (ppm) and flesh firmness (lb) found in individual McIntosh fruit stored in CA for 24 weeks and kept for 1 week at 68ºF before evaluation.

rence of superficial scald and a number of other storage-related problems. The possibility that MCP will eliminate reliance of the industry on the scald-inhibitor diphenylamine (DPA) and therefore avoid the need for the accompanying fungicide in the drench is particularly exciting.

Take Home Messages

The conclusions from our studies so far that will impact commercial success of MCP for the New York industry are:

1. Varieties differ greatly in their response to MCP, especially under air storage conditions. Successful use of MCP on varieties such as McIntosh may require a combination of good maturity information, especially internal ethylene concentrations, and CA storage. If permitted by label, higher MCP rates may be required. There is some evidence that results can be variable even within varieties (e.g. Delicious).
2. For some varieties, it is possible that MCP usage could replace CA storage. However, variations between year and harvest dates for varieties suggest that it is unlikely that MCP will become a replacement technology for CA storage. We believe that CA storage may be an essential backup to the use of MCP for seasons where MCP may be less effective. Nevertheless, for some varieties, MCP may permit extension of air storage periods and may be very useful to improve quality of fruit entering the marketplace in December.
3. Treating fruit warm may be more effective than treating fruit cold for some varieties, but this has a huge set of implications to current fruit handling systems.
4. MCP may eliminate the use of DPA.

We still have a lot to learn about this compound! MCP may have the impact equivalent to the development of CA storage on the apple industry. As with any

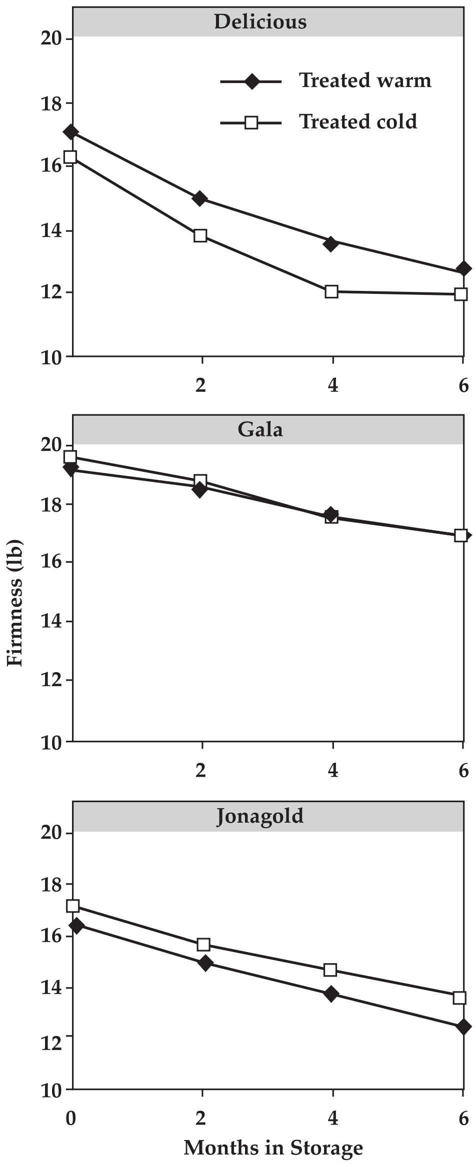

Figure 6. Flesh firmness (lb) of Delicious, Gala and Jonagold apples treated at harvest while warm or after overnight cooling to 32 ºF. Fruit were stored in air for 2, 4, or 6 months and evaluated after 1 week at 68ºF.

new product or technology, there may be downsides to the use of MCP. The cost factor is not yet known, but even if the cost of MCP is in addition to CA, the cost may be recovered by the stimulation of fruit sales if we get consumers to purchase more apples. Another issue of concern is the effect of MCP on volatile production associated with flavor, since inhibited ethylene production in aromatic apple varieties may be less desirable. However, the positive influence of MCP on maintaining the acid/sugar balance of fruit together with excellent texture qualities may more than compensate for lower aroma. As soon as MCP is registered for use, however, it will be essential that sensory analyses be carried out.

We have received funding from the New York Research and Development Program, the Apple Research Association and Rohm and Haas Company for research this coming season. Our primary goals for the coming two years are to focus on McIntosh and Empire. In addition, the New York Apple Association is applying to the Grow New York Program for matching funds to carry out research under commercial conditions. Our primary objective is that a year from now, when we hope that MCP will be registered, is to have enough information to help the New York industry make calculated decisions on how to best begin using the compound. The 2001 Storage Workshop in Ithaca will focus on application of MCP.

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