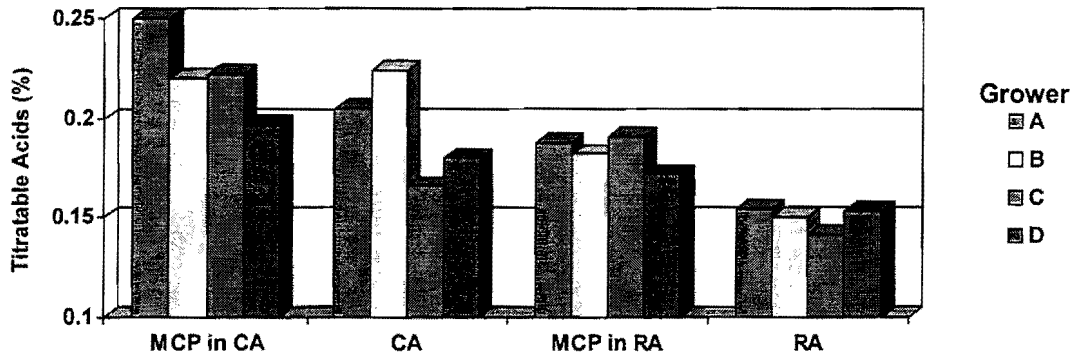
**Fig 2. 2000/2001 Commercial Trial – Titratable Acidity After 6 Months Storage**




The use rate is very low for 1-MCP, it has a non-toxic mode of action, and it is similar to the naturally occurring plant substance ethylene, giving it a very favorable safety profile. Studies demonstrate residues in apples are extremely low at below 5ppb. As an added benefit for apples, MCP also offers scald protection, delivering an alternative to current antioxidant treatments.

Semi-commercial and research trials conducted in various parts of the world indicate that 1-MCP offers dramatic results in firmness and titratable acidity, as well as protection from certain physiological disorders. A breakthrough in postharvest storage technology, 1-MCP will afford many fruit and vegetable industries the opportunity to deliver consistently high quality produce safely to the market. These benefits should be apparent all along the food chain.

# Use of 1-MCP on Apples

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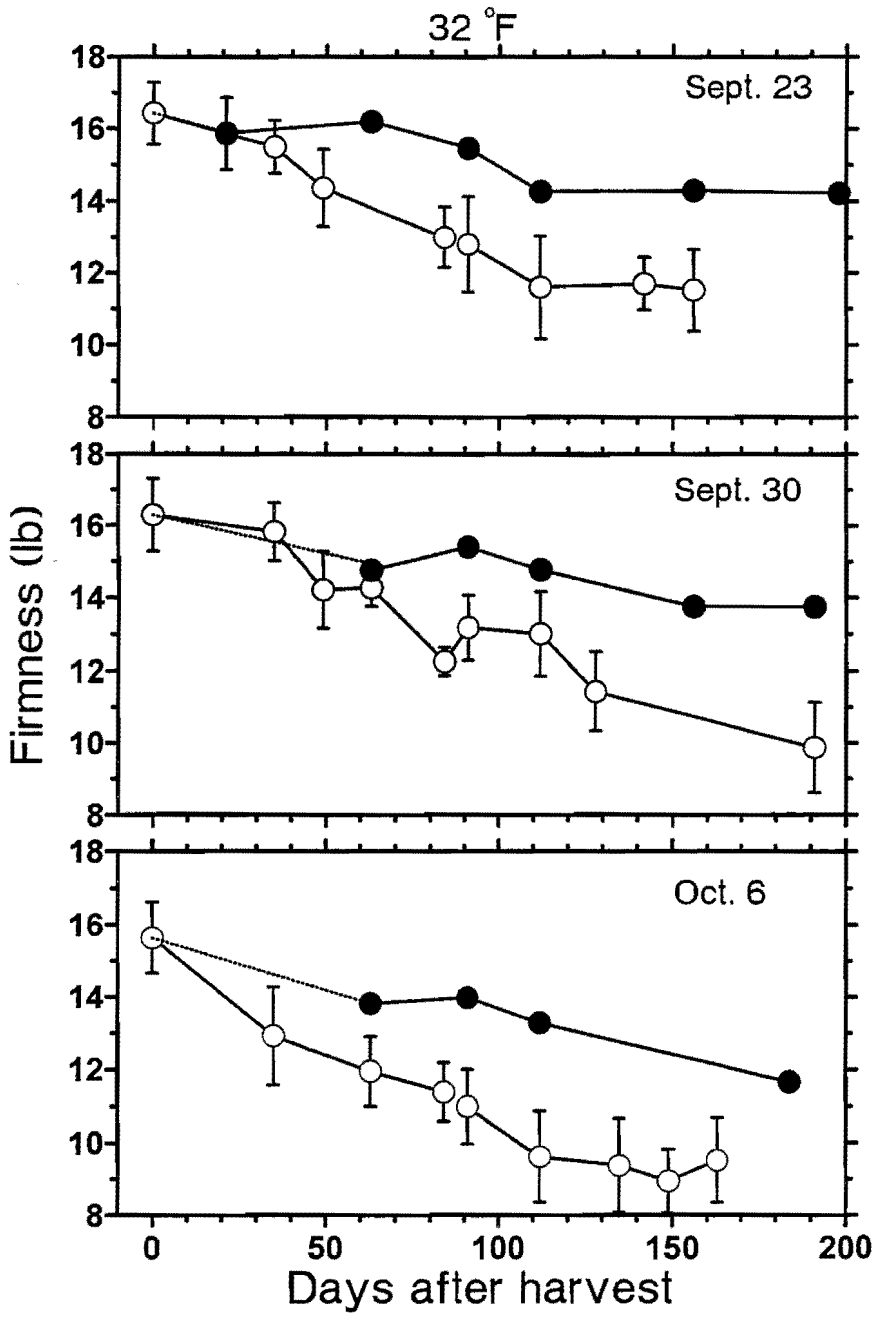
Many processes that occur during apple ripening, such as softening, yellowing, increased respiration and aroma production, are closely associated with ethylene. Senescence, the irreversible physiological changes that lead to cell death, follows ripening. While many of the ripening-associated processes that occur result in providing an acceptable product to the consumer, the goal of the storage operator is to reduce ethylene responses. Control of the onset and/or continuation of ripening and senescence provides the industry with a mechanism to maintain fruit quality. In fruit storage, management techniques used to minimize the effects of ethylene include low $O_2$, high $CO_2$, and reduced temperature.

## Apple responses to 1-MCP

A single exposure to 1-MCP can inhibit apple fruit sensitivity to ethylene. 1-MCP delays the onset of the rise in ethylene production and similarly delays the rise in respiration, aroma production, and softening (Figure 1). A single postharvest application could prevent ripening for an extended period (> 30 days), even at ambient temperatures (25°C, 77°F). 1-MCP also can inhibit aroma production in apple fruit and reduce the incidence of the storage disorder, superficial scald.

The response of apple fruit to 1-MCP depends upon a number of

Figure 1. Firmness (53.5 N = 12 lb) of 'Redchief Delicious' apple fruit treated at harvest with a single application of 0.7 ppm 1-MCP (solid symbols) or left untreated (open symbols). Fruit were harvested on three separate dates and held at 0°C (32°F) in air for up to 200 days. Vertical bars represent ± 1 standard deviation: bars are shown only for non-treated fruit for clarity, variation for treated fruit was similar.



variables. These variables include cultivar differences in response to 1-MCP and effects of fruit maturity. In addition, application technique, the exposure environment, and the storage environment (if different from the exposure environment) influence effectiveness of 1-MCP, although application techniques will be proscribed when the chemical is registered for commercial use. Good control of both harvest and postharvest variables will be needed to achieve a consistent response from 1-MCP.

For apple, it appears that the concentration of 1-MCP needed to be effective is between 0.25 and 1 ppm in the airspace around the fruit. The concentration needed to achieve maximum benefits may be slightly higher at higher treatment/ storage temperatures. The time needed for effective treatment appears to be relatively short and is between 12 and 16 hours, but varies according to cultivar. Accordingly, label recommendations for application will likely be for 24 hours. Repeated treatment of apple fruit with 1- MCP can improve the effectiveness of the material, but is unlikely to be economically feasible. A weekly application of 1-MCP prevented the softening of 'Redchief Delicious' apple fruit for over 120 days at 20°C (68°F). However, decay, while reduced relative to untreated fruit, is not inhibited by 1-MCP and can be a significant problem for fruit held at elevated temperatures. Furthermore, titratable acids and moisture (saleable weight) are lost rapidly at elevated temperature. Treatment with 1-MCP is not a substitute for cold storage, but may be useful for shorter periods at room temperature, especially for maintaining apple quality during shelf-life periods.

**Physiological Status.** The physiological status of the apple fruit is affected by a number of environmental, chemical and physiological factors. Apples tend to respond best when they are treated early in the ripening process in much the same way that less mature fruit tend to respond more favorably to controlled atmosphere storage relative to more mature fruit. The elevated levels of ethylene found during ripening in some fruit cultivars, such as 'McIntosh,' may be sufficient to reduce the effectiveness of 1-MCP. Therefore, those factors that enable treatment of the fruit with 1-MCP at an earlier stage of development, should improve or enhance the response of the fruit. For instance, cultural practices that enhance red color development relative to other maturity parameters (e.g., good light penetration into the canopy, application of ethylene synthesis inhibitors such as ReTain™, and cultivar selection) for red colored cultivars should provide growers with the potential to harvest at a less mature stage of fruit development.

**The storage envirionment influences the physiology of the apple fruit an also affects their responses to 1-MCP.**

If fruit are held in storage for a period of time prior to application of 1-MCP, the effectiveness of the gas declines. This is likely due to advances in fruit ripening prior to 1-MCP application. However, depending on cultivar, fruit may still respond to 1-MCP even after several months in storage if they are maintained in a relatively 'immature' condition by controlled atmosphere storage.

The storage environment influences the physiology of the apple fruit and also affects their responses to 1-MCP. As storage temperature increases, effectiveness of a single pre-storage application of 1-MCP declines. Ripening is delayed by roughly 30 to 40 days at room temperature, but the delay in ripening can be more than 100 to 200 days at 0°C (32°F).

Although cultivar greatly influences responses of apple fruit to 1-MCP (Table 1), the response of most apple cultivars is an immediate and relatively long-lived inhibition of ripening and other ethylene responses.

Physiological disorders of apple fruit (superficial scald, soft scald, core flush, greasiness, and senescent breakdown) can be reduced by 1-MCP application. Use of 1-MCP may allow storage operators to reduce usage of diphenylamine (DPA). However, caution should

Table 1: Responses of apple cultivars to 1-MCP, rated as low, moderate, and high. Cultivar responses may be affected by fruit maturity and by growing region, and therefore should be regarded as tentative (from Murr and DeEll, 2001, and Beaudry and Watkins, unpublished)

| Low | Moderate | High |
|---|---|---|
| McIntosh, Golden Delicious, Honeycrisp, Law Rome, Mutsu | Gala, Gingergold, Jonathan, Northern Spy, Sunrise | Cortland, Delicious, Empire, Fuji, IdaRed, Jonagold, Spartan |

be taken as DPA also inhibits carbon dioxide injury in susceptible cultivars, and 1-MCP has been reported to increase the susceptibility of treated apples to carbon dioxide injury. 1-MCP application has occasionally been associated with the development of superficial lesions or disorders on some apple fruit cultivars. Beneficial or detrimental effects of 1-MCP presumably depend on whether ethylene production, and associated ripening and senescence, is required for disorder development, e.g. scald and senescent breakdown, or whether normal ripening is required to prevent disorder development. In general, we would expect disorders associated with senescence to have a lower incidence in response to 1-MCP treatment.

## Factors to Consider Prior to Use

Ethylene is a natural hormone for the plant and, like other hormones, is involved in a number of physiological processes. Apart from inducing ripening-related changes in flavor and texture in climacteric crops such as apple, ethylene is known to play a role in pigment formation, chlorophyll degradation, decay resistance, phenolic metabolism, and other processes. There is potential to achieve desirable as well as undesirable responses of apple fruit to 1-MCP.

While some aspects of ripening are nearly completely arrested by timely application of 1-MCP, others not under complete control by ethylene may continue to change. The effect of 1-MCP on ripening parameters such as starch degradation and sugar accumulation is not as dramatic as its effect on firmness. This has important implications for fruit quality after storage. The impact of 1-MCP on aroma has also been measured. The compound induces a profound reduction in aroma production at concentrations >1 ppm; however, similar reductions in aroma occur in response to controlled atmosphere storage. The importance of such aroma reductions may be greater for some apple cultivars than others.

The advent of 1-MCP as a commercial tool has tremendous potential to help fruit industries maintain fruit quality. However, because of the long-reaching effects of 1-MCP on apple fruit, cautious adoption of this powerful tool is recommended. It will undoubtedly take a period of commercial experience to fully realize the benefits of 1-MCP for improving the quality of apple fruit in the marketplace.

**Further Reading**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# Responses of European Pears to 1-MCP

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As with other climacteric fruit, treatment with 1-MCP has been shown to slow ripening of many European pear cultivars. Cultivars tested at this time include 'd'Anjou,' 'Bartlett,' 'Bosc,' and 'Comice.' Typical responses include delays in degreening, softening, and loss of titratable acidity. Also, development of physiological disorders including senescent and superficial scald and internal browning may be delayed, reduced or even prevented by 1-MCP application.

However, 1-MCP does not reduce susceptibility to injuries resulting from exposure to low temperatures or high $CO_2$. While development of decay is slowed by 1-MCP treatment, fruit that are wounded and then inoculated with pathogen spores are not protected by a pre-inoculation treatment with 1-MCP. This indicates that decay resulting from injuries during harvest and packing may still require the use of other decay control measures.

Perhaps most importantly, unlike products such as apples and broccoli, European pears only reach full dessert quality when they ripen. This means that 1-MCP must be applied in such a way that the effects will, eventually, wear off. Unfortunately, the duration of 1-MCP-induced pear responses is difficult to precisely predict, and the effects of 1-MCP are not readily reversible by exposing treated fruit to ethylene. Factors that influence the duration of the effects of 1-MCP are now being studied. These include;

- treatment concentration,
- treatment time and temperature,
- fruit maturity, and
- the amount of time fruit is stored following 1-MCP treatment.

One of the desirable characteristics of 1-MCP is its activity at very low concentrations. Pear ripening can be retarded by very low concentrations of 1-MCP, while application of 1 ppm 1-MCP maximizes the effects. To test this, we treated pears with 0.01, 0.1, 0.5 or 1.0 ppm 1-MCP, then exposed the fruit to 100 ppm ethylene for 2 days at 20°C (68°F). Subsequent changes in firmness and color were measured at 2 day intervals. As shown in Figure 1a and b, the effects of 1-MCP on color and firmness are strongly concentration dependent within this range. Application of 0.1 ppm 1-MCP delayed ripening by approximately one day, while fruit exposed to 0.5 ppm softened nearly 3 times more slowly than the control and did not fully ripen for up to two weeks at 20°C (68°F). Exposure to 1 ppm 1-MCP resulted in fruit that still remained hard and green after over two weeks.