Use of 1-MCP on Apples*

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This research is supported in part by the New York Apple Research and Development Program.

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This is the first year 1-MCP (SmartFresh™) has been available to the US apple industry. New York storage operators, through impressive efforts by the industry and NY State DEC, were able to use SmartFresh commercially for the first time in 2002. Although CA storage rooms have just begun operating, the quality of treated fruit has been outstanding, especially after non-refrigerated post-storage periods. Clearly, this compound represents a revolution in our ability to provide higher quality fruit to the consumer.

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, cultural techniques used to minimize the effects of ethylene include low O_2, high CO_2 and reduced temperature (Abeles et al., 1992).

The growth regulator, 1-methylcyclopropene (1-MCP), has been shown to have significant promise as an ethylene action inhibitor (Sisler and Blankenship, 1996; Sisler et al., 1996). 1-MCP is classified as a growth regulator by the Environmental Protection Agency. In the US, it is approved for use in ornamentals under the trade name EthylBloc®, and under the commercial name, SmartFresh™, for application on apples and several other fruit. 1-MCP also is being extensively evaluated for use on many other crops.

Apple responses to 1-MCP

A single exposure to 1-MCP can temporarily render apple fruit insensitive to ethylene. 1-MCP delays the onset of the rise in ethylene production and similarly delays the rise in respiration, aroma production, and softening. A single postharvest application could prevent ripening for an extended period (> 30 days) at ambient (24°C or 75°F) temperature relative to non-treated controls (Fan et al., 1999; Mir et al., 2001). 1-MCP also dramatically inhibits aroma production in apple (Fan et al., 1999; Rupasinghe et al., 2000) and can reduce the incidence of superficial scald (Rupasinghe et al., 2000; Watkins et al., 2000).

The response of apple fruit to 1-MCP depends upon a number of variables. These variables include application technique, the exposure environment, the storage environment (if different from the exposure environment), cultivar sensitivity, and the physiological status of the crop. Control of these variables will be needed to achieve a consistent response of fruit to 1-MCP.

Application Technique

Application technique refers to the concentration, duration and frequency of application. 1-MCP concentrations required to saturate binding sites, and the extent and longevity of 1-MCP action, are influenced greatly by species, organ, tissue, and mode of ethylene biosynthesis induction. A 'time x concentration' effect is apparent, and the longer the exposure, the lower the required concentration.

Although 1-MCP binding is essentially irreversible, inhibition of ethylene action may be overcome by the production of new receptors (Sisler et al., 1996). 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. It is thought that the treatment time needed to achieve maximum benefits decreases as treatment temperature increases. Repeated treatment of apple fruit with 1- MCP can improve the effectiveness of the material, especially at elevated temperatures (Mir and Beaudry, 2001). 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 are lost rapidly at elevated temperature.

Since it is a gas, 1-MCP is applied in the air of the storage room, so air containing the 1- MCP has to be physically moved by blowers or existing fans. Air movement should be sufficient to rapidly and evenly distribute the gas.

Physiological Status. The physiological status of the apple fruit is affected by a number of environmental, chemical and physiological factors. It appears that apple fruit tend to respond best when they are treated early in the ripening process (Watkins et al., 2000; Mir et al., 2001) in much the same way that less mature fruit tend to respond more favorably to CA application relative to more mature fruit. There is some evidence to suggest that the elevated levels of ethylene found during

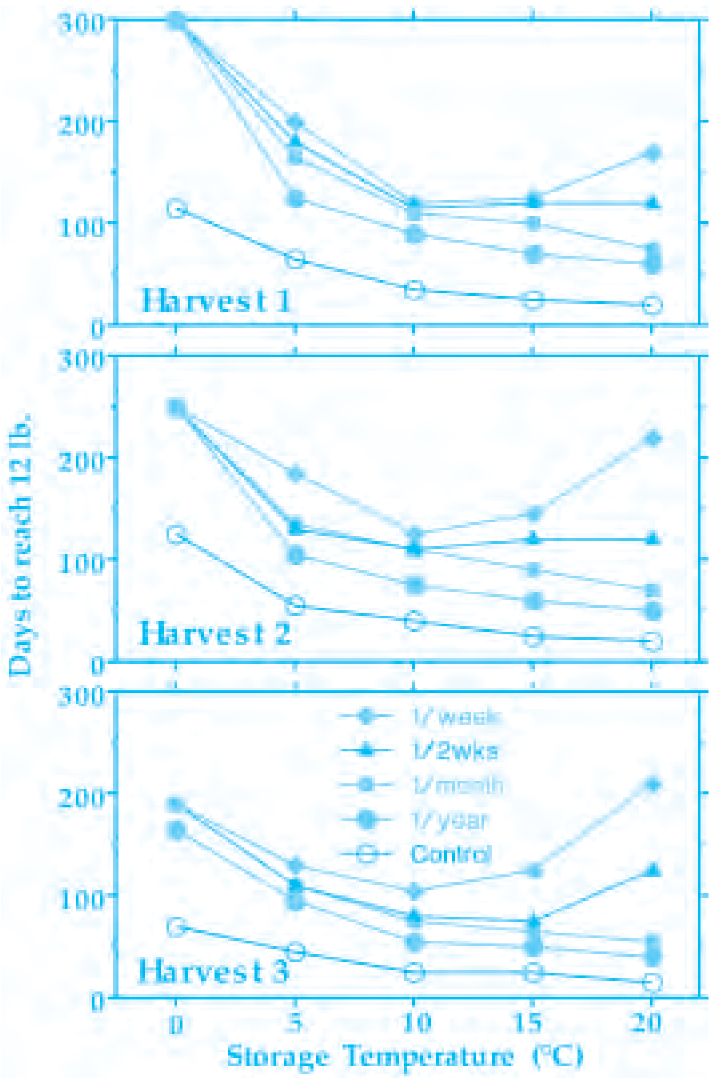

Figure 1. Estimates of days from harvest at which fruit would be expected to reach 53.5N (12 lb.) firmness based on linear regressions of time-dependent softening for 'Red Delicious' fruit harvested at weekly intervals (harvest 2 coincided with the onset of the ethylene climacteric) and given 1-MCP treatments on a once-per week (1/week), once-per-two-weeks (1/2wks), once-per-month (1/month), and once-per-year (1/year) basis and stored at 0, 5, 10, 15, and 20 °C

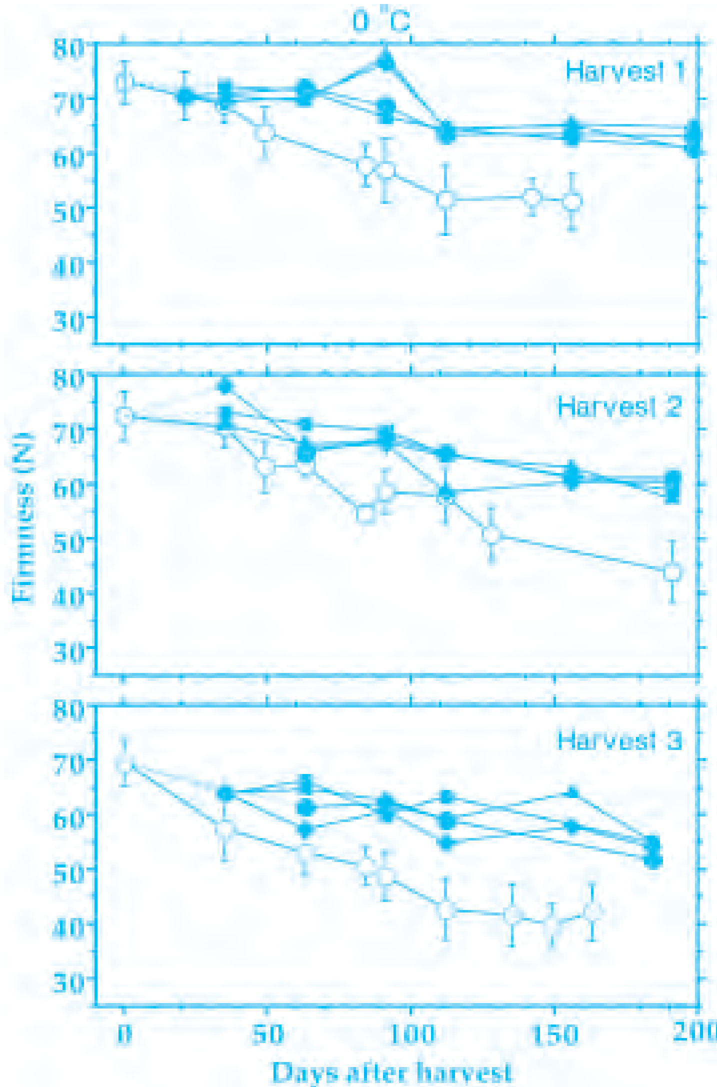

Figure. 2. Effect of 1-MCP on firmness loss of 'Redchief Delicious' apple fruit harvested 23 Sept. (harvest 1), 30 Sept. (harvest 2), and 6 Oct. (harvest 3) 1999 and stored continuously in air at 0°C. Treated fruit (closed symbols) were initially exposed to 0.7 $L \bullet L^{-1}$ 1-MCP for 16 h at room temperature and subsequently given weekly (1/week), bi-weekly (1/2 weeks), monthly (1/month) or no (1/year) additional treatments. Nontreated fruit (open symbols) were not exposed to 1-MCP. Each symbol represents 10 fruit, five from each of two replicate treatments. Vertical bars represent ±1 SD; bars are shown only for nontreated fruit for clarity, variation for treated fruit was similar.

ripening in some fruit varieties, such as 'McIntosh', may be sufficient to reduce the effectiveness of 1-MCP (Watkins et al., 2000). 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.

If fruit are held in storage for a period prior to application of 1-MCP, the effectiveness of the gas declines. This is likely due to the fact that the fruit are at a relatively advanced stage of ripening at the time of 1-MCP application. However, depending on variety, fruit may still respond to 1-MCP even after several months if they are maintained in a relatively 'young' condition by CA storage.

The storage environment influences the physiology of the apple fruit and so, too, affects the response to 1-MCP. As temperature increases, the duration of the effectiveness of a single pre- storage application of 1-MCP declines (Mir et al., 2001). 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) (Mir et al., 2001).

Although variety greatly influences responses of apple fruit to 1-MCP (Fan et al., 1999a; Rupasinghe et al., 2000; Watkins et al., 2000), the response of most varieties to 1-MCP is an immediate and relatively long-lived inhibition of ripening and other ethylene responses.

Physiological disorders of apple fruit (superficial scald, soft scald, coreflush, greasiness, and senescent breakdown) can be reduced by 1-MCP application (Fan et al., 1999b; Rupasinghe et al., 2000; Watkins et al., 2000). 1-MCP application has also been associated with the development of some forms of superficial lesions or disorders occasionally on some apple fruit cultivars. One concern is reports of increased susceptibility of 1-MCP-treated fruit to carbon dioxide injury.

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.

Factors to Consider Prior to Use

Ethylene is a natural hormone for the plant and, like other hormones, is required for or participates 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 in many tissues. These facts provide some indication of the potential to achieve desirable as well as undesirable responses from apple fruit.

While some aspects of ripening are nearly completely arrested by timely application of 1- MCP, others not under complete control of ethylene may continue to change. The effect of 1- MCP on ripening parameters such as starch degradation, sugar accumulation, and preservation of titratable acidity, is not as dramatic as its effect on firmness (Fan et al., 1999; Watkins et al., 2000; Mir et al., 2001). This may have important implications on fruit quality. In the case of apple, acidity contributes a significant portion of taste quality. It is possible that 1-MCP treated fruit, despite their firmness, may not maintain the tartness typical of some cultivars after extended storage. The impact of 1-MCP on aroma has been measured (Rupasinghe et al., 2000). The compound induces a profound reduction in aroma production at concentrations greater than 1 ppm. Flavor may be reduced by 1-MCP application, but many of these volatiles are undesirable in any case, being associated with over-ripening.

In addition to the problem posed by acidity loss, extensive decay has been encountered in 1-MCP treatments at elevated temperatures. While there is no published literature that suggests that apple fruit in particular may be more susceptible to decay in response to the suppression of ethylene action by 1-MCP, other plant species have exhibited increased susceptibility to some disease and decay causing pathogens. Some caution with regard to decay prevention is probably warranted even at the low temperatures of typical air or CA storage.

The advent of 1-MCP as a commercial tool has tremendous potential to help fruit industries maintain fruit quality. However, the effects of 1-MCP described thus far indicate that much remains to be learned before commercial use can be optimized.

References

Abeles, F.B., P.W. Morgan, and M.E. Saltveit, Jr. 1992. Ethylene in plant biology. 2nd ed. Academic Press, San Diego. Fan, X.

S. Blankenship, and J. Mattheis. 1999a. 1-Methylcyclopropene inhibits apple ripening. *J. Amer. Soc. Hort. Sci.* 124:690-695.

Fan, X., Mattheis, J.P. and Blankenship, S. (1999b) Development of apple superficial scald, soft scald, core flush, and greasiness is reduced by MCP. *J. Agric.Food Chem.* 47: 3063-3068.

Mir, N., E. Curell, N. Khan, M. Whitaker, and R.M. Beaudry. 2001. Harvest maturity, storage temperature, and 1-MCP application frequency alter firmness retention and chlorophyll fluorescence of 'Redchief Delicious' apples. *J. Amer. Soc. Hort. Sci.* 126:618-624.

Mir, N.A. and R.M. Beaudry. 2001. Use of 1-MCP to reduce the requirement for refrigeration in the storage of apple fruit. *Acta Hort.* 553:577-580.

Rupasinghe, H.P.V., D.P. Murr, G. Paliyath, and L. Skog. 2000. Inhibitory effect of 1-MCP on ripening and superficial scald development in 'McIntosh' and 'Delicious' apples. *J. Hort. Sci. Biotech.* 75:271-276.

Serek, M., E.C. Sisler, and M.S. Reid. 1994. A volatile ethylene inhibitor improves the postharvest life of potted roses. *J. Amer. Soc. Hort. Sci.* 119:572-577.

Sisler, E. and S. Blankenship. 1996. Method of counteracting an ethylene response in plants. U.S. Patent No. 5,518,988 (May 21, 1996). U.S. Patent and Trademark Office, Wash. D.C.

Sisler, E.C., E. Dupille, and M. Serek. 1996. Effect of 1-methylcyclopropene and methylenecyclopropane on ethylene binding and ethylene action on cut carnations. *Plant Growth Regulation* 18:79-86.

Watkins, C.B., J.F. Nock, and B.D. Whitaker. 2000. Responses of early, mid and late season apple cultivars to postharvest application of 1-methylcyclopropene (1-MCP) under air and controlled atmosphere storage conditions. *Postharvest Biol. Technol.* 19:17-23.

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