CURRENT AND FUTURE RESEARCH AND USES OF 1-MCP IN APPLES

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ABSTRACT

1-Methylcyclopropene (1-MCP), an inhibitor of ethylene perception, has been commercialized as SmartFresh™ technology for postharvest use on fruits and vegetables around the world. 1-MCP is used widely on apple fruit in North America; its successful commercial uptake has occurred because the technology helps to maintain quality of the fruit, not only during storage, but also through the entire marketing chain including the consumers’ homes. However, handling practices must take into account any factors that affect ethylene production. These factors include growing region, cultivar, maturity and ripening stage, time between harvest and treatment, and storage conditions. 1-MCP can reduce a number of serious storage disorders that cause fruit loss, such as senescent breakdown and superficial scald, but the incidence of others including carbon dioxide injury and flesh browning, can be increased by 1-MCP.

Keywords: ethylene, aminoethoxyvinylglycine, AVG, 1-methylcyclopropene, 1-MCP, ripening, physiological disorders

INTRODUCTION

1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene perception that can delay or prevent ripening and senescence processes in plant tissues (Sisler and Serek, 2003). The commercialization of 1-MCP as EthylBloc® and SmartFresh™ for floricultural and food products, respectively, has had a major effect on many horticultural industries around the world. 1-MCP has several features that have resulted in its rapid approval by regulatory authorities around the world – it is a gaseous chemical that is easily applied, it has a non-toxic mode of action, negligible residues, and activity at very low concentrations (Blankenship and Dole, 2003).

As of 2009, 1-MCP has been registered for commercial food use on a range of fruits and vegetables in 37 countries. The fruits and vegetables for which registration has been obtained include apple, avocado, banana, broccoli, cucumber, date, kiwifruit, mango, melon, nectarine, papaya, peach, pear, pepper, persimmon, pineapple, plantain, plum, squash and tomato; however, the number of products registered with each country varies greatly and according to the importance of the crop in that country. Of these products, the most successful to date for application of 1-MCP, has been the apple. In contrast, commercial application of 1-MCP to other products is not always straightforward. This is particularly true for those fruit that soften to a melting texture and/or have major color change during ripening, and therefore where a delay but not inhibition of ripening is
essential. Product type, the maturity of the product at the time of treatment, 1-MCP concentration and exposure time are all factors that are important in successful 1-MCP application for these fruits and vegetables (Watkins, 2006; Huber, 2008).

The apple has been an excellent crop for use of 1-MCP, and the technology is used extensively around the world to maintain quality through the whole marketing chain from the storage to the consumer (Watkins, 2006, 2008). The success of 1-MCP technology for apples is in no small measure because it is a fruit for which maintenance of ‘at harvest’ quality and only moderate softening to a crisp fracturable texture is desirable. 1-MCP is applied commercially as a postharvest treatment at present, but research and development on preharvest application, as the commercial product Harvista™, is ongoing.

In this presentation, my focus is on general principles for maximum effectiveness of postharvest 1-MCP application, and on its effects on physiological storage disorders.

POSTHARVEST APPLICATION OF 1-MCP

Much has been learned about factors that affect the efficacy of 1-MCP since its commercialization for use on apples in Chile and Argentina in 2002, New Zealand, South Africa and the United States in 2003, and rapid adoption of SmartFresh™ technology around the world. Factors that affect the effectiveness of 1-MCP include cultivar, fruit maturity, preharvest treatments, and postharvest handling, storage conditions (air, CA, temperature), and length of storage. These factors also interact with some cultivars to affect the incidence of physiological disorders.

Cultivar
There can be major differences in response to 1-MCP among cultivars (Bai et al., 2005; Dauny and Joyce, 2002; Fan et al., 1999; Rupasinghe et al., 2000; Watkins et al., 2000). McIntosh and Cortland are examples of cultivars for which control of ripening tends to be relatively short-lived, while the effects of 1-MCP on ripening of Delicious and Empire are more persistent (Fig. 1; Fan et al., 1999; Watkins et al., 2000; Watkins, 2008). However, regional differences are apparent, with the responses of the same cultivar being variable. Northern Spy, for example, showed little response to 1-MCP in New York (Watkins, 2008), but significant responses in Ontario, Canada (DeEll, pers. com.). It is possible that these differences reflect the effects of climate on the underlying physiology, such as the rate of ripening, but more likely, differences in internal ethylene concentration (IEC) at the time of harvest. The reasons for differences in cultivar responses in terms of ethylene receptor populations are under investigation (Taksuki et al., 2009).

Harvest maturity
Harvest maturity, especially in relation to IEC in fruit at the time of harvest, can greatly affect the responses of fruit to 1-MCP. The effects of maturity are illustrated using McIntosh harvested from Sept 10 to Oct 1. As harvest date progressed the starch index increased while fruit softened, and over this time, the IECs increased dramatically (Fig. 2). When fruit are harvested at intervals and then either untreated or treated with 1 ppm
1-MCP before cold storage, the effects of 1-MCP differed greatly during a 4 month storage period. In untreated fruit, the IEC increased rapidly during storage regardless of IEC at the time of harvest (Fig. 3). In contrast, the lower the IEC at the time of harvest, the greater the effectiveness of 1-MCP in delaying the increase of IECs and the softening of the fruit (Figs. 3 and 4).

**Preharvest treatments**
The effects of plant growth regulators on maturity, primarily via IEC, should also be major influences on the responsiveness of fruit to 1-MCP. Two preharvest chemicals that are commonly used for apples in New York are aminoethoxyvinylglycine (AVG), known commercially as ReTain® and naphthalene acetic acid (NAA) to prevent fruit drop from cultivars such as McIntosh. ReTain is typically applied 2-4 weeks before harvest and acts by decreasing ethylene production in the fruit and abscission zones of the stem. NAA is often applied as a rescue treatment drop is anticipated or has started, but can stimulate ethylene production by the fruit. Accordingly it is assumed that ReTain will improve responses of fruit to 1-MCP, while NAA will be detrimental. An example of this is an unpublished trial with Dr. Terence Robinson, Cornell University: ReTain (130 ppm), either 4, 3 or 2 weeks before anticipated harvest, and NAA (10 ppm), were applied McIntosh trees in the Hudson Valley, Champlain and western New York. Fruit were harvested on the optimum harvest day (H1) and then at weekly intervals for 2 weeks. The IEC of fruit at harvest was generally lower in ReTain-treated fruit, but increased in NAA-treated fruit (Fig. 5). After 3 months in air storage, fruit from H3 were softer than fruit from H1, and within each harvest date, fruit were firmer if treated with 1-MCP (Fig. 6). However, firmness ReTain treated fruit were either similar to, or firmer than, those that were untreated, while NAA-treated fruit were always softer and less responsive to 1-MCP.

**Postharvest handling**
Apples are a high volume crop and it typically takes several days to fill a controlled atmosphere (CA) room before the CA is applied. An early question was “what are the effects of delays after harvest and before 1-MCP application on fruit responses?” Watkins and Nock (2005) found that the importance of the number of days between harvest and treatment varied by cultivar and maturity stage. We have also found strong relationships between IEC increases in fruit during storage and the effectiveness of 1-MCP on maintaining firmness of fruit. In Jonagold, for example, there was an initial decrease of IEC when fruit were cooled but after 7 days, a marked increase of IEC (Fig. 7a). This increase was associated with a reduced response to 1-MCP (Fig 7b). Results such as this suggest that the more timely the 1-MCP treatment, the better the fruit response. The guidelines produced by AgroFresh typically suggest treatment of 7 days or less, although there are specific exceptions, e.g. where watercore is present. The current emphasis for management of 1-MCP is to attempt to treat fruit as quickly as possible after harvest and to place less stress on rapid CA. With McIntosh, we have found that there is no loss of firmness over 8 months of CA storage if fruit are treated with 1-MCP on the day after harvest and CA applied 2, 7 or even 14 days after treatment.
Storage conditions
Fruit treated with 1-MCP and stored in air can result in equivalent firmness maintenance as fruit treated with 1-MCP in CA storage (Watkins et al., 2000). Therefore it is possible to use 1-MCP to provide superior quality fruit in air storage, and this practice should be encouraged to ensure better quality fruit in the market in November and December. However, cultivar and maturity effects, as well as length of storage, can be critical, and in general we advocate 1-MCP use in conjunction with CA storage. This practice provides insurance if some fruit are less responsive to 1-MCP than others because of orchard block effects or other variables that affect the IECs.

PHYSIOLOGICAL DISORDERS

The effect of 1-MCP on physiological disorders has been reviewed (Watkins 2006, 2007). For apple, we can separate effects of 1-MCP into three categories:

1. Senescent-related disorders that are prevented by inhibition of ethylene production. An example is senescent breakdown.
2. Chilling-related disorders that are inhibited when ethylene production is prevented. An example is superficial scald.
3. Chilling-related disorders that are increased by inhibition of ethylene production. Examples are external carbon dioxide injury, and flesh browning.

Of these disorders, superficial scald, external carbon dioxide injury and flesh browning have received most attention.

Superficial scald
Superficial scald, sometimes known as storage scald, is a physiological disorder of certain apple and pear cultivars that is thought to be a chilling-related injury (Watkins et al., 1995). The disorder results in blackening or browning of the skin and was a major cause of fruit loss before the discovery and commercialization of diphenylamine (DPA). The current dogma for scald development is that α-farnesene production by the fruit and its subsequent oxidation to conjugated trienols (CTols) results in free radical reactions that damage cells of susceptible cultivars. The accumulation of α-farnesene in the skin is closely associated with ethylene production (Watkins et al., 1995).

It was found that 1-MCP inhibited scald and the accumulation of CTols (Fan et al., 1999; Rupasinghe et al., 2000; Watkins et al., 2000). In contrast with DPA, which has little effect on α-farnesene production but prevents its oxidation, 1-MCP prevents α-farnesene production by inhibiting ethylene and thereby reduces substrate available for oxidation. 1-MCP can be used to control scald commercially, reducing the need to treat fruit with a DPA (plus fungicide) treatment. However, the extent to which 1-MCP can be used for scald control can vary by cultivar and growing region, as well as postharvest handling procedures (Tsantili et al., 2007; Jung and Watkins, 2008).

External carbon dioxide injury
1-MCP treatment can increase the susceptibility of several apple cultivars to external (DeEll et al., 2003; Zanella, 2003; Watkins and Nock, 2004; Fawbush et al., 2008) and
internal (Mattheis, pers. com.) carbon dioxide injury. The reasons for increased sensitivity have not been established and require better understanding of the metabolic mechanisms of damage. The greatest period of injury risk occurs in the first few weeks of storage, and 1-MCP prevents the loss of sensitivity to carbon dioxide that occurs in fruit kept in air before CA storage (Fig. 8). However, DPA completely controls injury, and provides a safe and effective means to prevent injury development in cultivars such as Empire (Fawbush et al., 2008). External carbon dioxide injury can be reduced without DPA treatment, but special care is essential to avoid carbon dioxide accumulation during filling of rooms and during the first 4–6 weeks of storage.

**Flesh browning**

Flesh browning has been a long term problem during CA storage of some apple cultivars, including Empire. This cultivar is susceptible to chilling injury at storage temperatures close to 32°F. Current storage temperature recommendations are 35-36°F to minimize browning, but yet avoid the excessive softening found at 38°F. We have observed an unexpected and puzzling response of Empire fruit to 1-MCP treatment. If fruit are treated with 1-MCP, flesh browning incidence remains high and is little affected by storage temperature (Fig. 9). Interestingly, postharvest treatments such as delayed CA that decreased browning in untreated fruit had no effect on browning in 1-MCP treated fruit. Overall, our results indicated inhibition of ethylene production in the fruit is associated with higher browning incidence at warmer storage temperatures and that effective postharvest treatments to decrease injury are difficult to identify. We are continuing to investigate this phenomenon as answers to the problem are desperately needed by the NE apple industry.

**SUMMARY**

Application of 1-MCP technology has resulted in extensive research on apples around the world. It has become increasingly clear that handling practices in commercial practice must take into account any factors that affect ethylene production, both in terms of the timing of autocatalytic production and rates. These factors include growing region, cultivar, maturity and ripening stage, time between harvest and treatment, and storage conditions. The greatest challenge, however, lies in the effects of 1-MCP on physiological storage disorders such carbon dioxide injury and flesh browning, where we have learned how intimately ethylene production and action are associated with disorder-free storage of apples.

**REFERENCES**


Flesh firmness (N)

Fig. 1. Flesh firmness (N) of McIntosh (A) and Empire (B) apples treated with 1ppm 1-MCP and stored in air at 33°F for 4 months.
Fig. 2. Internal ethylene concentration, flesh firmness and starch index of McIntosh fruit during maturation on the tree.

Fig. 3. Internal ethylene concentration of fruit during storage in air at 33°F for 4 months without (A) and with 1ppm 1-MCP treatment (B) at harvest. Fruit were harvested at 3-4 day intervals from Sept 10 to Oct 1.
Fig. 4. Flesh firmness during storage in air at 33°F for 4 months without (A) and with 1ppm 1-MCP treatment (B) at harvest. Fruit were harvested at 3-4 day intervals from Sept 10 to Oct 1.
Fig 5. Internal ethylene concentration (ppm) of McIntosh apples treated with ReTain or NAA before harvest.

Fig 6. Flesh firmness (N) of McIntosh treated with ReTain or NAA before harvest and stored in air at 33°F for 3 months. Fruit were evaluated after 1 day at 68°F.
Fig. 7. (A) Internal ethylene concentration in Jonagold apple fruit at harvest and after 1, 7, 14 and 21 days at 33°F at the time of treatment with 1ppm 1-MCP, and (B) flesh firmness after storage in CA for 5 months, plus 7 days at 68°F.
Fig. 8. External carbon dioxide injury (%) of Empire apples exposed to 5% carbon dioxide one day after harvest, or untreated or treated with 1-MCP and exposed to carbon dioxide 2, 7 and 14 days after harvest.

Fig. 9. Flesh browning (%) of empire apples either untreated or treated with 1ppm 1-MCP and stored in CA for 9 months.