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Review Report

1-MCP Application for Horticultural Commodities in Korea: Practical Potential and Future Task

Youn-Moon Park*

Department of Food Science and Biotechnology, Andong National University, Andong 760-749, Korea

*Corresponding author: park123@andong.ac.kr

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Abstract. 1-methylcyclopropene (1-MCP), a gaseous inhibitor of ethylene action, has been widely used in horticultural crops to maintain quality, especially for long-term storage. In fruits, 1-MCP treatment reduces ethylene evolution, softening, color change, and flavor production, thus preserving product quality. The treatment also reduces the incidence of physiological disorders induced during refrigerated storage of many fruits and vegetables. Recent studies of 1-MCP treatments on various horticultural produce provided precious information that can expand the potential of commercial utilization. Under various treatment conditions, different responses to 1-MCP treatments were elucidated according to crops, cultivars, and harvest maturity. At present in Korea, however, commercial use of 1-MCP is limited to apple industry. The limit of commercial use of 1-MCP may be mainly due to different responses to the treatment by harvest maturity and storage conditions. Besides, diverse postharvest programs according to the period of storage require more specific treatment conditions such as concentration, temperature and the duration of treatment. In the present review, relatively recent research results were summarized and, based on the findings, future tasks were proposed to expand commercial usefulness of 1-MCP treatment in more horticultural commodities.

***Additional key words*:** ethylene action inhibitor, postharvest treatment, quality, softening, storage disorder

Introduction

In the area of postharvest technology, 1-methylcyclopropene (1-MCP) has been used as a potential tool to control quality changes in horticultural produce. 1-MCP is an ethylene action inhibitor, thus reducing quality deterioration during ripening and senescence of plants and the incidence of ethylene-related disorders.

The chemical was approved in USA as safe to human and environment by Environmental Protection Agency in 2002, and registered as a GRAS (generally recognized as safe) chemical by FDA in 2004.

The most obvious effect of 1-MCP treatment is the maintenance of flesh firmness and flavor in fruits (Mao et al., 2007; Park et al., 2009, 2011b; Pre-Aymard et al., 2005; Watkins et al., 2000) and vegetables (Cho et al., 2006; Lee et al., 2010) resulting in better consumer response (Marin et al., 2009). In contrast, longevity of life span is the major concern in ornamental plants (Kim et al., 2010c; Park et al., 2011a). Reduction of loss from physiological disorders is another benefit in fruits (Rupasinghe et al., 2000; Watkins et al., 2000). Such beneficial effects are not limited to climacteric type fruits but also observed in non-climacteric type fruits (Watkins, 2006) implying that 1-MCP can be used to control various deleterious effects from exogenous ethylene even in fruits and vegetables that do not produce ethylene by themselves over the critical level.

Conditions for the use of 1-MCP were well summarized in the review by Blankenship and Dole (2003). Treatment effects of 1-MCP vary according to commodity, commodity maturity, temperature, concentration, treatment duration, and lag time from harvest to treatment. A close relationship has been proposed between treatment duration and temperature. Relatively longer treatment duration is needed at low temperature. Usually, 1-MCP has been treated at 20-25℃. Effective concentrations also vary widely with commodities, time, temperature, and method of application. Some commodities such as peaches (Choi, 2005) and tomatoes (Lee et al., 2010) need multiple applications for continued inhibitory effects on ethylene action.

In Korea, studies of 1-MCP treatments started in late 1990's for ornamental crops and then expanded to fruits and vegetables in early 2000's. Numbers of experiments were conducted in a pilot scale, which needs practical test at the commercial scale in the near future. Among numerous scientific reports, relatively recent information was reviewed and core findings were briefly documented to suggest future tasks for the maximum use of 1-MCP.

Recent Researches on 1-MCP Treatment for Horticultural Crops in Korea

From a viewpoint of practical application, only a few researches are focused on the details of the treatment such as effective concentration and temperature. Most recent researches simply indicated the effects of 1-MCP treatment by applying at the 1 $\mu L \cdot L^{-1}$ concentration at room temperature. The treatment duration was usually 16 to 24 h (Table 1).

Apples

The most remarkable achievement of 1-MCP treatment might be the quality maintenance of apples. Beneficial effects of 1-MCP treatments have been reported in various apple cultivars in many countries (Bai et al., 2005; Marin et al., 2009; Mir et al., 2001; Pre-Aymard et al., 2005; Watkins et al., 2000). In Korea, 1-MCP is applied to 'Fuji' and Korean cultivars, such as 'Hongro' and 'Gamhong' apples.

For 'Fuji' and 'Hongro' apples, basic researches approved beneficial effects of 1-MCP on quality maintenance indicating the reduction of respiration and ethylene evolution while maintaining acidity and firmness (Bak et al., 2009; Lim et al., 2007, 2009; Park et al., 2009). Recent simulation studies indicated large potential of 1-MCP treatment for export programs in combination with controlled atmosphere (CA) storage. In the both cultivars, effects of 1-MCP and CA storage were additive to maintain flesh firmness (Park et al., 2009, 2011b).

Beside the effects on quality attributes such as acidity and firmness, 1-MCP seems to influence biochemical processes during ripening. Lim et al. (2009) indicated that 1-MCP treatment effectively reduced the skin greasiness of 'Hongro' apples, especially when stored at ambient temperature. Incidence of superficial scald, the predominant physiological disorder in apples, was reduced by 1-MCP treatment (Fan et al., 1999; Rupasinghe et al., 2000; Watkins et al., 2000). Exceptionally, 1-MCP could enhance carbon dioxide injury under CA conditions in susceptible cultivars (Fawbush et al., 2008). In the study of early-season Korean apples, Kweon et al. (2006) investigated different fruit responses to 1-MCP treatment as influenced by storage conditions and reported the risk of internal browning after high temperature storage.

For 'Gamhong' apples programmed for storage at ambient temperature, 2 $\mu L \cdot L^{-1}$ concentration was most effective for quality maintenance (Park and Jung, 2010) at ambient temperature. In contrast, 1 $\mu L \cdot L^{-1}$ 1-MCP treatment was satisfactory for quality maintenance during 6-month refrigerated storage (Park and Lee, 2011) suggesting that optimum concentration could be different by storage condition and period.

Pears

Effects of 1-MCP treatments on quality maintenance in Asian pears have been a controversial topic since some

Table 1. Experimental conditions of 1-MCP treatment used for major fruits and vegetables in Korea.

Commodity/cultivar	Concentration ($\mu L \cdot L^{-1}$)	Temperature (°C)	Duration (h)	Reference
Apple				
Fuji	1	20	16	Park et al., 2011b
Hongro	1	25	16	Park et al., 2009
	1	10	24	Lim et al., 2009
Gamhong	2	Ambient	24	Park and Jung, 2010
	1	20	16	Park and Lee, 2011
Pear				
Whangkeumbae	> 0.5	Ambient	4	Moon et al., 2008
Hwasan	1	Ambient	16	Park et al., 2010
Peaches	1	Ambient	16	Choi, 2005
			12	Chun et al., 2010
Plum	1	10	24	Lee et al., 2011
		20	16	Jung et al., 2010
Persimmon	1	Ambient	16	Choi, 2010
	5	20	12	Park and Yang, 2010
Tomato	1	12	Repeated, daily	Lee et al., 2010

Asian pear cultivars are classified as non-climacteric type and showed less response to 1-MCP. Nevertheless, recent researches proved positive effects on quality maintenance and the reduction of physiological disorders in 1-MCP treated pears (Moon et al., 2008a; Park et al., 2010; Wu et al., 2009).

Important implication came from the experiment on 'Hwasan' pears (Park et al., 2010). During 4- and 8-week storage, no differences in fruit quality were observed between 1-MCP treatment + 20℃ storage and non-treatment + 0℃ storage. The result suggests that 1-MCP treatment could replace cold storage when storage period is relatively short.

Studies of 1-MCP effects on pears confirmed the basic idea that inhibitory effects on the incidence of physiological disorders may vary by harvest maturity (Moon et al., 2008a, 2008b; Oh et al., 2009).

Stone Fruits

Effects of 1-MCP on peach fruit also vary by cultivars, harvest maturity, and storage conditions. In one of white peach, 'Baekhyang', effect of 1-MCP treatment is temporary and not sufficient for quality maintenance, thus repeated treatments are needed to prevent ethylene action during storage (Choi, 2005). In another white peach, 'Mibaek', in contrast, single treatment of 1-MCP exerted effects on quality maintenance during 16-day storage in combination of MAP (Park and Yang, 2011). In yellow peach, 'Janghowon Hwangdo', beneficial effects of 1-MCP treatment last very short period of storage only in mature fruit (Chun et al., 2010). Minimum concentration for effective use seemed to be 1 $\mu L \cdot L^{-1}$. Researches on peach fruit suggest relatively limited effects of 1-MCP on quality maintenance and needs of repeated application for beneficial effects during long-term storage.

Responses of plums to 1-MCP treatment were slightly different from those in peaches. No significant differences in treatment effects on the quality maintenance were observed among various harvest maturity (Lee et al., 2011). Delay of treatment time by less than one day did not reduce beneficial effects (Jung et al., 2010). Inhibitory effect on the incidence of chilling injury could extend the storage ability of plums at lower temperature (Bae et al., 2011). Studies of 1-MCP treatment on plums also suggest a useful idea that 1-MCP treatment can replace refrigeration during 14-day shelf life (Jung et al., 2010) as was proposed in apples (Park and Jung, 2010) and pears (Park et al., 2010).

Persimmon

In sweet persimmon, firm and crisp texture is a critical quality factor for consumers' preference. Despite little amount of endogenous ethylene production in sweet persimmons, softening occurs rapidly on the shelf at ambient temperature, especially after long-term storage. Treatment of 1-MCP on 'Fuyu' persimmons remarkably retarded softening on the shelf, which suggests a large potential for export to tropical countries (Choi, 2010). Relatively high concentration of 1-MCP was suggested for sufficient effectiveness during long-term storage (Park and Yang, 2010). Since the fruit are very sensitive to exogenous ethylene (Park and Lee, 2006), beneficial 1-MCP effect is also expected when persimmon fruit are transported or displayed with ethylene-evolving commodities.

Fruit Vegetables

Tomato is a typical climacteric fruit and very sensitive to ethylene. Endogenous or exogenous ethylene enhances ripening processes which are effectively inhibited by 1-MCP treatment (Wills and Ku, 2002). The response of tomatoes to 1-MCP treatment, however, is different from that observed in other fruits. Tomato needs repeated or continuous treatments for continued delaying effects on ripening (Lee et al., 2008, 2010) probably because of regeneration of ethylene receptors (Blankenship and Dole, 2003).

Positive effects of 1-MCP treatment for melon (Cha et al., 2006; Kim et al., 2010a), fresh squash (Lee et al., 2006), and green beans (Cho et al., 2006) were also reported at research level. 1-MCP application at 1.0 $\mu L \cdot L^{-1}$ concentration delayed ripening of melons, thus extending shelf life (Cha et al., 2006). Postharvest life of fresh squash and green bean pod was also prolonged by 1-MCP at the concentration of 0.5 $\mu L \cdot L^{-1}$.

Ornamentals

For ornamentals, the main purpose of 1-MCP treatment is the extension of vase life in cut flowers and life span of potted plants. Application of 1-MCP inhibited wilting and rolling response of cut iris prolonging vase life by 0.5 day (Kim et al., 2010c). In contrast, effects of 1-MCP treatment on potted kalanchoe plants may vary by cultivars or by environmental factors. Limited and minimal effects on postharvest life were observed in some kalanchoe cultivars (Park et al., 2011a; Serek and Reid, 2000), whereas, in 'Tropicana' cultivar, 1-MCP delayed exogenous ethylene-induced senescence (Serek et al., 1994). Park et al. (2011a) observed significant effect of silver thiosulfate (STS) treatment rather than 1-MCP and suggested the idea of regeneration of ethylene receptors and the different mechanism of treatment effects between the two ethylene action inhibitors.

Practical Use of 1-MCP Treatment for Postharvest Handling Program

At present, commercial application of 1-MCP has been

Table 2. Estimation of storage potential for the export program of early season Korean cultivar, 'Hongro' apples.

Postharvest program		Storage potential for export[z]
Harvest maturity	1-MCP treatment	
Optimum	None	Shorter than 3 months
	1 μL·L[-1]	4 months
Delay	None	2 months
	1 μL·L[-1]	4 months

[z]Export simulation: 2-week shipment by refrigerated container + local distribution at ambient temperature for 7 days.

Table 3. Estimation of storage potential for the export program of late season cultivar, 'Fuji' apples.

Postharvest program		Storage potential for export[z]
Harvest maturity	1-MCP treatment	
Optimum (Before Oct. 25)	None	4 months
	1 μL·L[-1]	Longer than 8 months
Slightly delayed[y] (Around Oct. 30)	None	Shorter than 4 months
	1 μL·L[-1]	7 months

[z]Export simulation: 2-week shipment by refrigerated container + local distribution at ambient temperature for 7 days.
[y]Data were modified from Park et al., 2011b.

successively performed in apples for both the domestic and export markets. Results from simulation studies (Park et al., 2009, 2011b) were summarized and developed into postharvest handling programs. By 1-MCP treatment, export period extended for 1 to 2 more months in early season apple (Table 2) and for 4 more months in late season apple (Table 3). The extension effects were more remarkable in late harvested early season cultivar.

Commercial utilization of 1-MCP is limited in pears because of relatively lower benefits from the treatment. However, needs of 1-MCP treatment may increase in some pear cultivars to prevent physiological disorders such as internal browning and flesh pithiness (Moon et al., 2008a; Wu et al., 2009).

Large practical potential is also expected in MA-stored sweet persimmons as a feasible treatment technique develops for small unit packages (Ahn and Choi, 2010).

Prospective Task for the Maximization of Benefits from 1-MCP Treatments

Optimization of Treatment Conditions

Detailed complementary studies should be directed to determine the minimum concentration sufficing the treatment purpose considering harvest maturity, the time of treatment and temperature. The concentration may also vary according to the target period of storage.

Expansion of Applicable Crops

Potential of 1-MCP treatment is continuously investigated through experiments on various horticultural crops (Cho et al., 2012; Choi et al., 2012; Kim et al., 2010b) or through indirect implications from postharvest studies. Effects of exogenous ethylene on berry shattering in grapes (Hong et al., 2009, 2010) and softening in sweet persimmon (Park and Lee, 2006) also suggest the potential use of 1-MCP to reduce quality deterioration during mixed shipment for export.

Although 1-MCP itself has not been used to control ethylene-related quality deterioration and incidence of disorders, experiments are being conducted to elucidate the effects of ethylene or ethylene removal on the quality changes during storage of various crops. Some studies reported that ethylene absorbing agents or inhibitors improved storage potential suggesting the usefulness of 1-MCP by replacing the absorbent and inhibitors. In this regard, beneficial effects of 1-MCP treatments are expected in ginger (Chung et al., 2010).

Technical Approach to Replace Refrigerated Storage

As indicated by recent studies, 1-MCP seems to replace cold storage when storage period is shorter than 1 month (Jung et al., 2010; Park and Jung, 2010; Park et al., 2010). If it were so, 1-MCP can be applied to more fruits and vegetables that are programmed to be stored for transient period before distribution or export shipment. From an economic point of view, storage at ambient temperature without refrigeration will save energy and provide more profits by using 1-MCP.

Maximization of Storage Potential in Combination of Other Skills

Another task to maximize the potential of 1-MCP treatment is the approval of the 1-MCP effect during long-term storage. Answers to the task were partly already has come from the study of export simulation of apples after long-term storage (Park et al., 2009, 2011b). 1-MCP treatment in combination of CA storage exerted additive effects on quality maintenance, thus prolonging storage life (Watkins et al., 2000) and export period (Park et al., 2009, 2011b).

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