

# Postharvest Application of 1-Methylcyclopropene (1-MCP) Extends Shelf Life of Kiwifruit

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## Abstract

The role of postharvest application of 1-methylcyclopropene (1-MCP) in the softening of 'Hayward' kiwifruit under different cold storage conditions was investigated. 1-MCP treated fruit (0.0, 0.5, 1.0  $\mu\text{l L}^{-1}$ ) were kept in cold storage (1°C) up to 6 months before ripening. Different 1-MCP application times were also tested in this trial (12 and 24 h). Effect of 1-MCP under ethylene-free atmosphere and under ethylene contaminated atmosphere during storage was investigated. Under both conditions, 1-MCP treatment significantly delayed the rate of fruit softening during cold storage. Firmness out of cold storage was significantly increased by 1-MCP treatments. Moreover, the number of days of shelf life at 20°C (after 4 and 6 months of cold storage at 1°C) needed by 'Hayward' kiwifruit to reach a flesh firmness  $\leq 10$  N was significantly increased by 1-MCP postharvest treatment. These data show that 1-MCP treatment recommendations for an optimal result depend on both the length of cold storage as well as ethylene contamination of the atmosphere during storage.

## INTRODUCTION

The ethylene action inhibitor 1-MCP, which blocks the ethylene receptors, has been extensively studied to regulate fruit ripening in both climacteric and non-climacteric fruits (Dong et al., 2002; Jung and Lee, 2009; Khan and Singh, 2009; Larrigaudière et al., 2009). Effect of 1-MCP on delaying softening of fruit has been reported to depend upon the fruit maturity stage at harvest (Valero et al., 2003), concentration applied (Salvador et al., 2000), duration of fruit exposure to 1-MCP (Abdi et al., 1998; Dong et al., 2002), method of application (Khan and Singh, 2009; Manganaris, 2007), storage conditions and fruit temperature at the time of 1-MCP application (Abdi et al., 1998).

The objectives of this work were to evaluate the role of postharvest application of 1-MCP in modulating market life under different storage conditions, and find the best 1-MCP concentration and exposure time to be applied for kiwifruit.

## MATERIAL AND METHODS

### Plant Material and 1-MCP Application

Kiwifruit (*Actinidia deliciosa* 'Hayward') were harvested, transported to the laboratory, and immediately placed in hermetically sealed steel tanks (330 L) at 1°C and different concentrations of 1-MCP (0.0, 0.5, 1.0  $\mu\text{l L}^{-1}$ ) and durations (12 or 24 h). 1-MCP was obtained from AgroFresh Inc. (SmartFresh Quality System). Following the 1-MCP treatments, half of the fruit from each treatment combination were stored in a cold room with 1.0  $\mu\text{l L}^{-1}$  ethylene (external contamination), and the other half in a room with an air exchange of one tank volume per 6 h in order to remove any ethylene produced by the fruit, both at 1°C.

### Fruit Firmness

After 0, 2, 4 and 6 months of storage at 1°C (with or without ethylene), 1 box from each treatment was moved to 20°C to be evaluated during shelf life. 10 fruit from each treatment were evaluated for flesh firmness every 2 days until softening reached 10 N.

Fruit firmness was determined by a penetrometer fitted with an 8-mm tip. After

removing a thin slice of fruit skin (~3 mm), firmness was recorded from both sides of each fruit and means were expressed as Newtons (N).

### Statistical Analysis

All statistical analyses were performed using SPSS 17.0 for Windows (SPSS, Chicago, IL, USA). Duncan's multiple-range test ( $P \leq 0.01$ ) was used to estimate treatment means and to find differences among them.

## RESULTS

As expected, contamination with ethylene during the cold storage accelerated the decrease of fruit firmness of both fruit treated or non-treated with 1-MCP (Table 1 and Figs. 1 and 2). However, treatment with 1-MCP extended the shelf life of kiwifruit by maintaining firmness both in fruit free of ethylene and in fruit contaminated with ethylene ( $1.0 \mu\text{l L}^{-1}$ ) during the cold storage time, for all the storage time tested (60, 120 and 180 d) (Table 1). This result demonstrates that treatment with 1-MCP induces an extension of shelf life of fruit even if the fruit suffer from contamination of ethylene during the cold storage due to the ethylene production by other commodities. After 120 d of storage, no significant differences in terms of fruit flesh firmness out of the storage were found among different 1-MCP treatments (Table 1). Therefore, a 1-MCP concentration of  $0.5 \mu\text{l L}^{-1}$  treatment during an exposure time of 12 h is recommended for cold storage periods up to 60 d.

However after 120 d of cold storage, significant differences were found among different 1-MCP concentration and exposure time combinations (Table 1). In the fruit free of ethylene during all the storage duration,  $1.0 \mu\text{l L}^{-1}$  1-MCP treated fruit (for 12 or 24 h) showed the highest firmness after 120 d of cold storage at  $2^\circ\text{C}$ , without being significantly different from fruit treated with  $0.5 \mu\text{l L}^{-1}$  for 12 h. However, when the fruit was contaminated with ethylene during the cold storage, both 1-MCP treatments with a longer exposure time ( $0.5$  and  $1.0 \mu\text{l L}^{-1}$  for 24 h) showed the highest fruit firmness after 120 d of cold storage. Thus, inhibition of ethylene effects on ripening by binding to ethylene receptors is better achieved by 1-MCP when the exposure time is longer. Therefore, 24 h of exposure would be recommended when the fruit is thought to be stored with ethylene-producing commodities, whereas 12 h of exposure would be enough when kiwifruit is thought to be free of ethylene contamination during storage.

After 180 d of cold storage, all 1-MCP treatments increased the firmness of the fruit (Table 1) although no significant differences were found on fruit firmness between different 1-MCP treatments just after removing the fruit from cold storage. However, differences became significant during shelf life at  $20^\circ\text{C}$ .

The firmness evolution of kiwifruit during shelf life at  $20^\circ\text{C}$  after 60, 120 and 180 d of cold storage was also improved by 1-MCP treatments.

After 4 months, the ethylene-free fruit did not show consistent differences in terms of fruit firmness among different 1-MCP treatments. However, untreated fruit softened much faster than 1-MCP treated fruit, reaching less than 10 N of flesh firmness at day 4 of shelf life, whereas 1-MCP treated fruit showed firmness higher than 10 N until the day 10 of shelf life (results not shown). Therefore, 1-MCP treatments showed an extension of shelf life of about 6 days on the kiwifruit not contaminated with ethylene during the cold storage. The lack of consistent differences among different 1-MCP treatments, points out  $0.5 \mu\text{l L}^{-1}$  of 1-MCP applied on the fruit during 12 h as the best treatment to be applied on kiwifruit that is going to be ethylene-free during storage.

Treatment with 1-MCP also showed a dramatic effect on the firmness evolution of kiwifruit during shelf life after 120 d of cold storage. Untreated fruit had a firmness value below 5 N out of cold storage, whereas fruit treated with 1-MCP maintained a flesh firmness value above 10 N approximately until day 8 of shelf life at  $20^\circ\text{C}$ . Besides that, there were significant differences among 1-MCP treatments in terms of fruit softening. Differences seen in the firmness out of the cold storage were maintained consistently along the whole shelf life period, showing that 24 h of exposure to 1-MCP has beneficial

effects on the maintenance of firmness in kiwifruit contaminated with ethylene during storage. Thus, as commented above, treatment with  $0.5 \mu\text{L}^{-1}$  of 1-MCP with an exposure time of 24 h is the treatment recommended for kiwifruit suspected to be contaminated by ethylene from other commodities during cold storage.

Similar results were found after six months of cold storage (Fig. 1). 1-MCP treated fruit showed significantly higher firmness at all the times measured during shelf life (from day 0 to day 8) on both ethylene-free (Fig. 1a) or ethylene-contaminated fruit (Fig. 1b). However, the effect of different 1-MCP treatments on the softening of the fruit was very similar, without showing significant differences between different concentrations or application times. This could be due to the fact that, immediately after the cold storage period, the 1-MCP treated fruit firmness was already around 10-12 N, and therefore the range of softening to find differences between treatments was much lower than after 4 months.

It is important to notice that although firmness was maintained by 1-MCP during storage, the treatment does not prevent the softening of the fruit during shelf life to reach a proper firmness for consumption.

The number of days of shelf life at  $20^{\circ}\text{C}$  needed to reach the minimum firmness value acceptable for consumption ( $\leq 10$  N) after 180 days of cold storage at  $2^{\circ}\text{C}$  is shown in Figure 2. Results are similar to what happened after four months of cold storage, although in that case the fruit was firmer. Untreated fruit firmness was below 10 N when came out from the cold storage, either with or without ethylene contamination during storage. On both the ethylene-free (Fig. 2a) and ethylene-contaminated fruit (Fig. 2b), fruit treated with  $0.5 \mu\text{L}^{-1}$  of 1-MCP applied for 24 h showed the higher number of days to reach 10N. No improvement was achieved when applying higher concentration ( $1 \mu\text{L}^{-1}$  24 h). However, an extension of shelf life resulted from treating the fruit during 24 h when compared to the treatment for 12 h. Therefore, after 180 d of cold storage, the best results were achieved when treating the fruit with  $0.5 \mu\text{L}^{-1}$  of 1-MCP applied for 24 h, no matter if the fruit was or not stored in a free or ethylene-contaminated atmosphere.

## CONCLUSIONS

The results of this work show that treatment with 1-MCP extended the shelf life of kiwifruit by maintaining firmness both in fruit free of ethylene and in fruit contaminated with ethylene ( $1.0 \mu\text{L}^{-1}$ ) during the cold storage time up to 4 months. This means that treatment with 1-MCP induces an extension of shelf life of kiwifruit even if the fruit suffer from contamination of ethylene during the cold storage due to the ethylene production by other commodities.

The results of this work also show that the 1-MCP protocol to follow to extend the shelf life of kiwifruit depends on the length and type of storage that is going to be performed with the fruit. For short periods of cold storage (up to 60 d), the lack of improvement of the 1-MCP treatment when applying higher concentrations, or for longer periods of time, points out that  $0.5 \mu\text{L}^{-1}$  of 1-MCP during 12 h applied just after harvest would be the recommended protocol to use. On the other hand, when the period of time to be stored is longer than 60 days, the protocol to follow it will depend on if the fruit is free of ethylene contamination during cold storage or not. If the fruit will be stored with no any other commodity, and potential ethylene contamination in the storage atmosphere is going to be removed, an application of  $0.5 \mu\text{L}^{-1}$  of 1-MCP during 12 h will be the best protocol to follow on kiwifruit. However, if the fruit is suspected to be in contact to ethylene produced either by the kiwifruit or by other commodities in the same cold room, 1-MCP exposure time should be increased to 24 h, and slightly better results would be obtained by increasing also the concentration to  $1 \mu\text{L}^{-1}$ .

Optimization of postharvest applications of 1-MCP on the kiwifruit, and the beneficial effects of this practice on the shelf life of this commodity has been achieved with this work.

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## Tables

Table 1. Effect of 1-MCP on the 'Hayward' kiwifruit flesh firmness (N) after 60, 120 and 180 days of cold storage (1°C). Fruit were treated with different 1-MCP concentration and application time combinations. Treatments were split into two sub-treatments: fruit exposed to air with a flux of 1 L/min during storage (no ethylene exposure), and fruit exposed to 1.0 µl L<sup>-1</sup> ethylene with a flux of 1 L/min during storage. Data are means of ten replicates.

Treatment	Firmness (N)		
	after 60 d cold storage	after 120 d cold storage	after 180 d cold storage
No ethylene exposure during cold storage			
Control	20.46 b	11.79 c	7.45 b
1-MCP 0.5 µL L <sup>-1</sup> (12h)	32.92 a	15.57 ab	10.90 a
1-MCP 1 µL L <sup>-1</sup> (12h)	31.47 a	17.46 a	12.01 a
1-MCP 0.5 µL L <sup>-1</sup> (24h)	29.91 a	13.01 bc	12.23 a
1-MCP 1 µL L <sup>-1</sup> (24h)	31.14 a	16.35 a	11.57 a
Ethylene exposure during cold storage			
Control	3.38 b	4.45 c	2.78 b
1-MCP 0.5 µL L <sup>-1</sup> (12h)	30.14 a	11.23 b	11.01 a
1-MCP 1 µL L <sup>-1</sup> (12h)	28.25 a	11.34 b	11.68 a
1-MCP 0.5 µL L <sup>-1</sup> (24h)	24.69 a	13.90 a	10.56 a
1-MCP 1 µL L <sup>-1</sup> (24h)	26.91 a	13.90 a	11.23 a

For each sub-treatment (with or without ethylene exposure during cold storage), means with the same letter are not significantly different according to Duncan's test ( $P \leq 0.01$ ).

## Figures

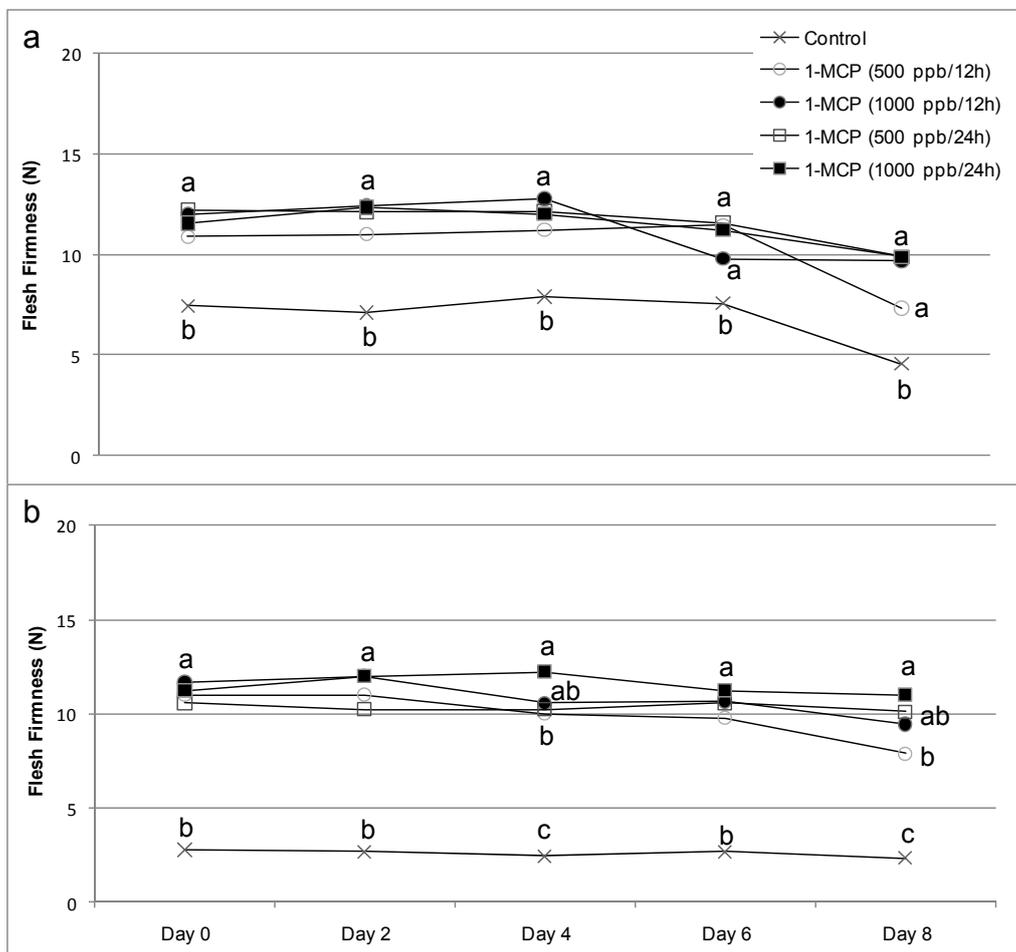


Fig. 1. Effect of 1-MCP on the flesh firmness evolution of 'Hayward' kiwifruit during 12 days at 20°C after 180 d of cold storage (1°C). During cold storage, (a) air was continuously renovated (1 L/min) to prevent exposure of the fruit to ethylene; (b) fruit was exposed to 1.0 µl L<sup>-1</sup> ethylene with a flux of 1 L/min. Each data point is the mean of ten replicates.

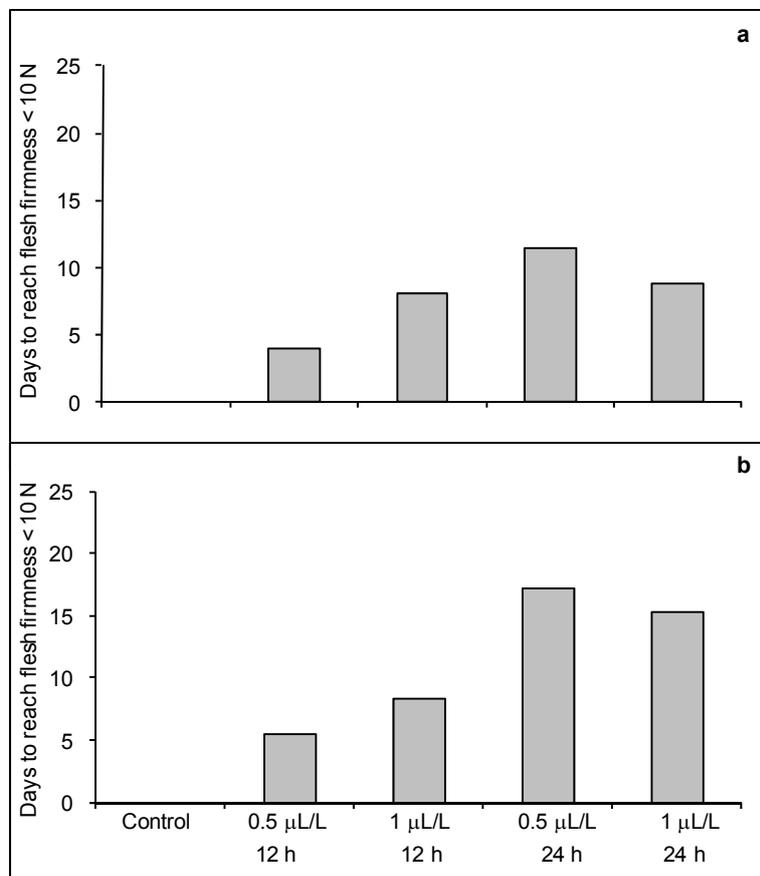


Fig. 2. Effect of 1-MCP on the number of days at 20°C (after 180 d of cold storage at 1°C) needed by 'Hayward' kiwifruit to reach a flesh firmness  $\leq 10$  N. During cold storage, (a) air was continuously renovated (1 L/min) to prevent exposure of the fruit to ethylene; (b) fruit was exposed to 1.0  $\mu\text{l L}^{-1}$  ethylene with a flux of 1 L/min. Number of days to reach a flesh firmness  $\leq 10$  N was calculated from the average of ten replicates.