Dual preharvest application of 1-methylcyclopropene (1-MCP) aqueous spray controls mango (Mangifera indica L. cv. ‘Carabao’) ripening

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The Philippine ‘Carabao’ mango (Mangifera indica L. cv. ‘Carabao’), one of the major fruit exports of the country, poses difficulties in the control of its ripening due to induction of ethylene biosynthesis before harvest maturity at about 100 days after flower induction (DAFI). To control its ripening after harvest, the ethylene antagonist, 1-methylcyclopropene (1-MCP) was applied as an aqueous spray at 10 ppm concentration to on-tree mango fruits at 100 DAFI. Four (4) sets of fruits were tagged for a second round of 1-MCP spraying. One set was sprayed the second time at 105 DAFI, while the remaining sets at 110, 115 and 120 DAFI respectively. The positive control was sprayed with water only while the negative control was not sprayed. The fruits were harvested at 120 DAFI and stored at 13°C. Mango fruits sprayed at 100 then at 115 DAFI showed significantly slowest peel color development and deterioration in visual quality among the other treatments and controls. This treatment also exhibited significantly least disease severity. Firmness did not vary significantly among treatments. Occurrence of the peak in ethylene production after harvest was delayed for 4 days with the treatment sprayed at 100 then at 115 DAFI compared with the control fruits. Dual preharvest application of 1-MCP, first at 100 then at 115 DAFI was able to control ripening of mango and extend shelf-life to about 4 days. To the best of our knowledge, this is the first study on a dual preharvest application of 1-MCP as an aqueous spray on the Philippine ‘Carabao’ mango.

INTRODUCTION

The Philippine ‘Carabao’ mango (Mangifera indica L. cv. ‘Carabao’) is one of the most important fruit crops of the country. Control of its ripening after harvest has been a major challenge, especially if it is to be exported, because ripening occurs very rapidly once it has been initiated. Events associated with ripening of ‘Carabao’ mango initiate in the mesocarp prior to full maturation and with ethylene production showing a peak at about 10 days before harvest maturity (Cua 1989). This indicates that ripening is initiated in the inner mesocarp prior to full maturation. This could be the reason why attempts to maintain the mature ‘Carabao’ mango fruits at the pre-climacteric stage to delay ripening has proven futile. Controlling ethylene production before the fruit reaches full maturation, that is, while it is still on-tree, could be effective in delaying ripening.

The ethylene antagonist 1-methylcyclopropene (1-MCP) effectively blocks the hormone action of ethylene, by binding permanently to ethylene receptors in plant tissues (Sisler and Serek 1997). The affinity of 1-MCP for the receptor is approximately 10 times greater than that of ethylene. Compared with ethylene, 1-MCP is active at much lower concentrations (Blankenship and Dole 2003). Eventual recovery of tissue to

KEYWORDS
1-methylcyclopropene, ‘Carabao’ mango, ethylene production, preharvest spray, horticulture, postharvest physiology
respond to ethylene is apparently via the synthesis of new ethylene receptors (Adkins et al. 2005).

The ability of 1-MCP to prevent ethylene action in a range of climacteric and some non-climacteric fruit including apple, apricot, avocado, banana, custard apple, mango, papaya and strawberry, is now well established (Blankenship and Dole 2003). 1-MCP exposure is accomplished via treatment as a gas in sealed containers as originally described by Serek et al. (1994). Application 1-MCP in the form of an aqueous solution has also proven to be effective. Aqueous applications of 1-MCP has shown to control ethylene action in tomato and avocado (Choi et al. 2008), apple (Elfving et al. 2007) and citrus (Burns 2008). While these forms of application have been designed to facilitate broader agricultural applications of ethylene-action suppression, these formulations also have uses in postharvest situations where facilities suitable for delivery as a gas are not readily available (Choi et al. 2008). In on-tree preharvest applications, 1-MCP in the form of aqueous spray formulations could be of practical use. A 1-MCP preharvest aqueous spray of 10 ppm concentration at 100 days after flower induction (DAFI) on ‘Carabao’ mango on-tree yielded slowest rate softening, peel color development and visual quality decline (Castillo-Israel et al. 2014a). 1-MCP was also found to effectively block ethylene in ‘Carabao’ mango at this maturity stage (Castillo-Israel et al. 2014b).

This study aimed to control ethylene production in Carabao mango prior to its upsurge before harvest maturity, through application of aqueous 1-MCP to mango fruits on-tree. Subsequent spraying at different maturity stages of the fruits was also done to determine whether such treatments would be more effective in controlling ethylene by blocking newly synthesized receptors.

MATERIALS AND METHODS

The experiments were conducted on a mango farm in Barangay Siranglupa, Calamba City, Laguna, Philippines. 1-MCP was applied as an aqueous spray to ‘Carabao’ mango fruits on-tree. The 1-MCP used was a gift from Dr. Xiang Chun Meng from Guangdong Academy of Agricultural Sciences, China. The formulation contains 0.43% 1-MCP. Triton-X which served as surfactant, was added to the amount of 0.25 mL/L. Spraying was done within 30 mins after the preparation of the spray solution. The first spraying was carried out using 10 ppm 1-MCP at 100 DAFI. Mango fruits on the tree at 100 DAFI were unbagged then sprayed with 10 ppm 1-MCP solution. The fruits were then enclosed in plastic bags for 2h to allow time for binding of 1-MCP. The plastic bags were then removed and the fruits were again bagged with paper. Color tags were placed on each paper bag to facilitate identification of treatments (Figure 1). From these sprayed fruits, four (4) sets of fruits consisting of sixty (60) fruits per set were tagged for a second round of 10ppm aqueous 1-MCP spraying. Thus, one set was sprayed the second time at 105 DAFI (100, 105 DAFI), while the remaining sets at 110, 115 and 120 DAFI respectively. The positive control was sprayed with 0 ppm 1-MCP using distilled water plus surfactant while the negative controls were the unsprayed fruits.

All fruits were harvested at 120 DAFI, stored at 13°C, and monitored for ripening parameters such as firmness, peel color index (PCI), visual quality rating (VQR), disease severity and ethylene production.

Peel Color Index (PCI), Visual Quality Rating (VQR) and Disease Severity

Monitoring of PCI, VQR and disease severity was done using the routine protocol of the Postharvest Horticulture Training and Research Center (PHTRC) which involved visual evaluation by an individual throughout storage using a standard scale. PCI was monitored using the scale as shown in Figure 2. VQR was monitored as follows: 9,8 – excellent, field fresh; 7,6 – good, defects minor; 5,4 – fair, defects moderate; 3 – poor, defects serious, limit of saleability; 2 – limit of edibility; 1 – non-edible under usual conditions. Disease severity was monitored using the following scale: 1 – none (0%); 2 – slightly infected (5-10% of fruit surface affected); 3 – moderate (15-30% of fruit surface affected); 4 – severe (>30% of fruit surface affected). For these analyses, 3 replicates were used consisting of 5 fruits per replicate.

Figure 1. Preharvest application of aqueous 1-MCP spray. (a) Mango fruits were unbagged (b) sprayed with aqueous 1-MCP (c) enclosed in plastic bags for 2 hours (d) bagged again with tagged paper bags.

Figure 2. VQR was monitored as follows: 9,8 – excellent, field fresh; 7,6 – good, defects minor; 5,4 – fair, defects moderate; 3 – poor, defects serious, limit of saleability; 2 – limit of edibility; 1 – non-edible under usual conditions. Disease severity was monitored using the following scale: 1 – none (0%); 2 – slightly infected (5-10% of fruit surface affected); 3 – moderate (15-30% of fruit surface affected); 4 – severe (>30% of fruit surface affected). For these analyses, 3 replicates were used consisting of 5 fruits per replicate.
Ethylene production measurement
Fruits were weighed and then enclosed in respiration jars for 1 h after which, 1 mL gas samples were collected. The gas samples were injected into a Shimadzu model 80A gas chromatograph with flame ionization detector (GC-FID). Peak heights for ethylene and the standard were measured after injection. Ethylene production was calculated as:

$$nL \text{ C}_2\text{H}_4 \text{ g}^{-2} \text{ h}^{-1} = \frac{(\text{peak sample})}{(\text{peak std})} \times \frac{1}{\text{mL}} \times \frac{1}{t} \times \frac{1}{\text{wt}} \times V_f$$

Fruit Firmness
Firmness of unpeeled fruits was obtained quantitatively using a hand-held penetrometer (MF push-pull scale; max. limit of 100 lbs; graduation of 0.5 lbs). To get the firmness or resistance to deformation, the penetrometer plunger was pressed perpendicularly against the sample enough only to sink the whole pointed part of the plunger. Fruits were punctured at 3 points in the middle portion of the cheeks. Firmness was reported as kg-force.

Statistical Analysis
Each experiment was carried out under a completely randomized design with three replications repeated at least twice. Data was analyzed using SAS Statistical Software (SAS Institute Inc., Cary, NC, USA) by Tukey’s Test at 5% level.

RESULTS AND DISCUSSION

Peel color changes and decline in visual quality
Significant differences in peel color changes were observed with 100, 115 DAFI treatment compared with both the negative and positive controls starting at 6 days until 21 days storage (Table 1). The other 1-MCP treatments also had slower peel color development compared with the controls but the differences were not significant. Delays in peel color development were observed starting at 6 days where the 100, 115 DAFI treatment still remained at PCI 1.14 while the rest are between 1.5 to 2. Significant difference in PCI were observed in 100, 115 DAFI compared with the controls starting at 13 days. This delay was carried over until 21 days where the PCI is 5.24 for the 100, 115 DAFI treatment, about 5.5 for the rest of the 1-MCP treatments, and the negative control already at PCI 5.90, the 100, 115 DAFI varying significantly with the negative control. After which, all the samples reached PCI 6 at almost the same rate. Comparing the negative and positive controls and the 100, 115 DAFI treatment, a delay of about 4 days in peel color development was observed in the 100, 115 DAFI. The controls reached PCI 5 at about 14 days while the 100, 115 DAFI treatment reached the same PCI at about 18 days. Similar delay in peel color development caused by 1-MCP were also observed in other mango cultivars such as ‘Guifei’ (Wang et al., 2006) and ‘Nam dok-mai’ (Penchaiya et al., 2006).

Visual quality started to decline at 7 days (Table 2). Significant difference in VQR of 100, 115 DAFI treatment from the positive and negative controls were observed starting at 21 days until 26 days. The VQR scores of the other 1-MCP treatments in general, however, did not vary significantly with the control. Significantly lower VQR was obtained with 100, 120 DAFI treatment from 6 days until 17 days. This was due to severe lenticel spotting (data not shown). This suggests that spraying right before harvest results to lower visual quality of fruits caused by severe lenticel spotting which develops during the early stage of ripening.

| Table 1. Peel color index (PCI) of mango fruits sprayed at preharvest with 10 ppm 1-MCP at 100 DAFI with reapplication at 105, 110, 115 and 120 DAFI, harvested at 120 DAFI and subsequently ripened at 13°C. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Treatment       | 1               | 4               | 6               | 7               | 11              | 13              | 17              | 19               | 21               | 24               | 26               |
| Negative control| 1.00a           | 1.05a           | 1.71a           | 2.38a           | 3.48a           | 4.38a           | 5.43a           | 5.48a            | 5.90a            | 5.95a            | 6.00a            |
| Positive control| 1.00a           | 1.05a           | 1.71a           | 2.38a           | 3.48a           | 4.33a           | 5.24a           | 5.43a            | 5.62ab           | 6.00a            | 6.00a            |
| 100 DAFI        | 1.00a           | 1.05a           | 1.43ab          | 1.43b           | 3.14b           | 4.10ab          | 4.95ab          | 5.05a            | 5.57ab           | 5.86a            | 6.00a            |
| 100, 105 DAFI   | 1.00a           | 1.00a           | 1.29ab          | 1.52b           | 3.00b           | 4.10ab          | 5.00ab          | 5.19b            | 5.67ab           | 6.00a            | 6.00a            |
| 100, 110 DAFI   | 1.00a           | 1.00a           | 1.48ab          | 1.96ab          | 3.05b           | 4.05ab          | 5.05ab          | 5.19b            | 5.52ab           | 5.90a            | 6.00a            |
| 100, 115 DAFI   | 1.00a           | 1.05a           | 1.14b           | 1.57b           | 3.10b           | 3.71b           | 4.71b           | 5.10b            | 5.24b            | 5.81a            | 5.86a            |
| 100, 120 DAFI   | 1.00a           | 1.00a           | 1.33ab          | 1.48b           | 3.57a           | 4.00ab          | 5.05b           | 5.48ab           | 5.76ab           | 6.00a            | 6.00a            |

Each value is a mean of three replicates, each replicate consisting of five fruits. Values with the same letter among treatments at each sampling period are not significantly different based on Tukey’s test, P=0.05.

| Table 2. Visual quality rating (VQR) of mango fruits sprayed at preharvest with 10 ppm 1-MCP at 100 DAFI with reapplication at 105, 110, 115 and 120 DAFI, harvested at 120 DAFI and subsequently ripened at 13°C. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Treatment       | 1               | 4               | 6               | 7               | 11              | 13              | 17              | 19               | 21               | 24               | 26               |
| Negative control| 9.00a           | 9.00a           | 9.00a           | 8.43a           | 8.00a           | 7.81b           | 7.33bc          | 6.57c           | 5.86d           | 5.10c           | 3.81d           |
| Positive control| 9.00a           | 9.00a           | 9.00a           | 8.71bc          | 8.33ab          | 8.05ab          | 8.11ab          | 7.57ab          | 7.19c           | 5.86bc          | 4.86cd          |
| 100 DAFI        | 9.00a           | 9.00a           | 9.00a           | 8.76bc          | 8.05a           | 8.05ab          | 8.05ab          | 7.67a           | 7.48b           | 6.90bc          | 6.00abc         |
| 100, 105 DAFI   | 9.00a           | 9.00a           | 9.00a           | 8.67bc          | 8.19b           | 8.14ab          | 7.86b           | 7.81b           | 7.52b           | 6.71ab          | 6.14ab          |
| 100, 110 DAFI   | 9.00a           | 9.00a           | 9.00a           | 8.57bc          | 8.14a           | 8.10ab          | 7.90b           | 7.86a           | 7.52b           | 6.52bc          | 5.95bc          |
| 100, 115 DAFI   | 9.00a           | 9.00a           | 9.00a           | 8.35bc          | 8.19b           | 8.00ab          | 8.00ab          | 7.95a           | 7.90a           | 7.11c           | 6.86a           |
| 100, 120 DAFI   | 9.00a           | 9.00a           | 9.00a           | 8.10c           | 7.86b           | 7.29c           | 7.10c           | 7.05bc          | 6.62d           | 5.95abc         | 5.05bc          |

Each value is a mean of three replicates, each replicate consisting of five fruits. Values with the same letter among treatments at each sampling period are not significantly different based on Tukey’s test, P=0.05.
Disease Severity

Significantly low disease severity was observed in all the 1-MCP treatments at 21 days compared with the controls (Table 3). The 100,115 DAFI treatment exhibited the slowest disease development which commenced at about 24 days, while the controls, 100 DAFI and 100, 120 DAFI treatments were observed to have diseases at 13 days. The rest of the treatments developed diseases at 17 days. At about 24 days, the 100,115 DAFI treatment had significantly lower disease severity (1.10) compared with the controls (2.29 for the negative control and 2.00 for the positive control) until 26 days. Thus, 1-MCP seemed to have a positive effect in terms of increasing the resistance of fruits to disease-causing organisms, with its reaplication proving to prolong the effect.

Likewise, Zhang et al. (2012) has shown that 1-MCP effectively limited the development of lesion diameter of blue mold rot and significantly reduced the incidence of natural decay in jujube fruit. Disease incidence and severity of diseases in tomatoes caused by Alternaria alternatae, Botrytis cinerea, and Fusarium spp. in 1-MCP treated fruit was also significantly reduced compared with that of the untreated controls (Su and Gubler 2012). 1-MCP was also observed to influence pathogen infection and development in ripe goldenberries (Gutierrez et al. 2008). However, in another cultivar of mango, the ‘Kensington pride’, 1-MCP caused doubled severity of stem rots (Hofman et al. 2001).

The control of decay exhibited by 1-MCP could be correlated to its effect on delayed fruit softening. The softening of fruit tissues as a result of the breakdown of pectic substances produces smaller sugar molecules such as monosaccharides and oligosaccharides which serve as substrates of microorganisms. Also, breakdown of the cell wall consequently results to leakiness of the cell membrane resulting to loss of nutrients from the cell. These nutrients are made available to microorganisms for their growth.

Fruit firmness

A rapid decline in firmness was observed in all treatments until PCI 3 (Table 4). High firmness of 1-MCP treated fruits compared with controls were observed at PCI 2 except 100, 120 DAFI which exhibited the lowest firmness (1.88). In the transition from PCI 3 to PCI 4, the 1-MCP treatments had the slower decline in firmness compared with the controls. Firmness values were also higher for the 1-MCP treated fruits (0.87-0.97) compared with the controls (0.58-0.68). This is the stage of mango at which the highest rate of softening is expected. Thus, 1-MCP seemed to slow down the softening process in mango. Same were observed in other fruits such as McIntosh and Delicious apples (Rupasinghe et al. 2000), ‘Elberta’ peaches (Fan et al. 2002). Softening during ripening in climacteric fruit is generally attributed to degradation in cell wall assembly, particularly the solubilization of pectin. These changes could involve increased activities of various cell wall hydrolases, the activities of which, are up-regulated by ethylene (Lohani et al. 2004). Thus, 1-MCP as an ethylene blocker, hampers the softening process.

Ethylene production

Peaks in ethylene peaks were observed in all treatments (Table 5). Earlier onset at 13 days were observed in 100,110 DAFI (0.58 nL C2H4 g−1 h−1) and 100,120 DAFI (0.50 nL C2H4 g−1 h−1)
Table 5. Ethylene production at the attainment of PCI in mango fruits preharvest treated with 10 ppm 1-MCP at 100 DAFI with reapplication at 105, 110, 115 and 120 DAFI. Fruits were harvested at 120 DAFI and ripened at 13°C.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative control</td>
<td>0.44</td>
<td>0.17</td>
<td>0.09</td>
<td>0.44$^{12}$</td>
<td>0.62$^{15}$</td>
<td>0.00</td>
</tr>
<tr>
<td>Positive control</td>
<td>0.23</td>
<td>0.22</td>
<td>0.07</td>
<td>0.56$^{12}$</td>
<td>0.75$^{16}$</td>
<td>0.37</td>
</tr>
<tr>
<td>100 DAFI</td>
<td>0.36</td>
<td>0.06</td>
<td>0.08</td>
<td>0.23$^{13}$</td>
<td>0.70$^{17}$</td>
<td>0.04</td>
</tr>
<tr>
<td>100, 105 DAFI</td>
<td>0.31</td>
<td>0.07</td>
<td>0.03</td>
<td>0.26$^{13}$</td>
<td>0.51$^{17}$</td>
<td>0.00</td>
</tr>
<tr>
<td>100, 110 DAFI</td>
<td>0.26</td>
<td>0.07</td>
<td>0.03</td>
<td>0.58$^{13}$</td>
<td>0.48$^{17}$</td>
<td>0.00</td>
</tr>
<tr>
<td>100, 115 DAFI</td>
<td>0.10</td>
<td>0.12</td>
<td>0.05</td>
<td>0.40$^{14}$</td>
<td>0.46$^{19}$</td>
<td>0.11</td>
</tr>
<tr>
<td>100, 120 DAFI</td>
<td>0.00</td>
<td>0.07</td>
<td>0.04</td>
<td>0.50$^{13}$</td>
<td>0.38$^{17}$</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Superscripts indicate the number of days required to reach the specific PCI. Only values at PCI 4 and 5 are indicated because these correspond to the peak in ethylene production. Each value is a mean of three replicates, each replicate consisting of two fruits. Values among treatments at each PCI are not significantly different based on Tukey’s test, P<0.05.

Figure 3. Visual quality of mango fruits sprayed at preharvest with 10 ppm 1-MCP, harvested at 120 DAFI and subsequently ripened at 13°C.
treated with 1-MCP can be observed in 100, 105 DAFI; 100, 110 DAFI and 100 DAFI treatments which took place at 17 days except for the 100, 115 DAFI (19 days).

Preharvest 1-MCP application caused a slight delay in the onset of ethylene peaks by 2-4 days which is an evidence of inhibition of ethylene autocatalysis. The threshold ethylene level inside tissues is not reached due to the binding of 1-MCP to ethylene receptors ahead of ethylene molecules. As an effect, it is possible that ethylene just diffused readily out of tissues, causing delayed accumulation of ethylene in tissues, thus a delay in ethylene autocatalysis.

On the effect of a second 1-MCP application, in general, it was able to effectively lower ethylene production as proven by the lower ethylene peaks exhibited by the treatments with dual 1-MCP application. The second 1-MCP application at 115 DAFI was able to delay the onset of the ethylene peak by 2 days. The initial effect of ethylene inhibition by 1-MCP at 100 DAFI was not sustained. Reapplication was necessary in order to provide new 1-MCP molecules to bind with the new and unbound receptors present a few days after the first application. The other treatments with dual application did not exhibit a delay in the peak onset however, but only lowered peaks. The time of reapplication is critical due to the changing biochemical composition of the tissues. It was shown that the second application was most effective at 115 DAFI. This illustrates that about this time the level of ethylene in tissues are low while abundant unbound receptors and newly synthesized ones are present.

The time of application of 1-MCP proved to be critical to achieve ethylene-blocking effects. The time at which ethylene dissociates from receptors, the degradation of receptors, the synthesis of new receptors, and the possibility that 1-MCP dissociates from receptors are factors which determine the effectiveness of 1-MCP application. Kevany et al. (2007) provided evidences that receptors are degraded by ethylene. Likewise, evidences also show the new receptors are synthesized as the fruit matures. Sisler et al. (1996) demonstrated that 1-MCP binds irreversibly to ethylene receptors and suggest that plants eventually overcome inhibition by making new receptors. Jayanty et al. (2004) also proposed that secondary applications could serve to occupy pre-existing receptors from which 1-MCP has dissociated. Therefore a second application of 1-MCP reinforces its initial ethylene-blocking effects.

Figure 3 shows the mango fruit samples harvested at 120 DAFI and subsequently stored at 13°C. A marked delay in ripening and disease development can be noted in mango fruits twice treated with 1-MCP. Comparable delayed ripening effects of 1-MCP can be observed in 100, 105 DAFI; 100, 110 DAFI and 100, 115 DAFI treatments. The 100 DAFI treatment which was treated with 1-MCP only once, and 100, 120 DAFI treatment which received a 1-MCP treatment at 100 DAFI and another treatment right before harvest, showed comparable rates of deterioration and disease development with the control fruits. These results prove that dual applications of 1-MCP starting at 105 DAFI until 115 DAFI can control ripening by sustaining the effect of the initial application at 100 DAFI. The initially bound 1-MCP could have dissociated or new receptors formed, thus the second application of 1-MCP becomes necessary.

Generally, fruits harvested in more advanced maturity stages are less susceptible to 1-MCP application, as also observed in ‘Tommy Atkins’ mangoes at S3 maturity stage are not significantly affected by 1-MCP applications. (Alves et al. 2004). Similarly, 1-MCP did not suppress senescence in fruit harvested at the yellow stage of maturity of ‘Galia’ type melon (Gal et al. 2006). At more advanced maturity stages, ethylene production has also surged its peak and has bound to ethylene receptors as well. Therefore, ethylene induced ripening responses has already commenced. Application of 1-MCP would no longer be effective in blocking ethylene due to the saturation of the receptors with ethylene prior to its application. Upon harvest of the fruits treated with 1-MCP at the mature stage, ripening will proceed with minimal delay. This study has demonstrated the effectiveness of applying 1-MCP before harvest maturity in order to control ripening. The application was effectively carried out prior to the surge in ethylene before harvest maturity, and was even enhanced by a secondary application.

**SUMMARY AND CONCLUSIONS**

In this study, the efficacy of dual preharvest application of 1-MCP as an aqueous spray on mango fruits on-tree was demonstrated. The time of the second 1-MCP reapplication is crucial because the biochemical composition of tissues varies at any one time. Significant delays of about 2-4 days in peel color development and visual quality deterioration were observed in treatments with dual applications of 1-MCP compared with the treatment with only a single 1-MCP application and the controls. Disease development was likewise significantly hampered by dual applications. Fruit firmness did not vary significantly among treatments. Ethylene production in the treatment with single 1-MCP application and the controls were higher compared with the treatments with dual 1-MCP treatments. The time at which the ethylene peak occurred was almost the same for all 1-MCP treatments except that which received a second 1-MCP application at 115 DAFI after initial application at 100 DAFI. The onset of the ethylene peak for this treatment was delayed for 4 days compared with the controls. It is also evident in the appearance of the fruits that this treatment exhibited delayed ripening. Therefore, mango fruit ripening can be controlled using 1-MCP as a tool by blocking ethylene induced ripening, through its dual preharvest application as an aqueous spray with 10 ppm concentration, first at 100 DAFI then at 115 DAFI.

**ACKNOWLEDGEMENTS**

The authors would like to acknowledge The National Institute of Horticultural and Herbal Science (NIHHS) of the Rural Development Administration (RDA) of the Republic of Korea.
and the Department of Science and Technology Science Education Institute (DOST-SEI) of the Philippines for the funding.

CONFLICTS OF INTEREST

None

CONTRIBUTIONS OF AUTHORS

Dr. Katherine Ann T. Castillo-Israel, the lead author, conducted all the experiments both in the field and in the laboratory. She conducted all the data gathering and analyses as well as the writing of this manuscript. The results shown in this paper are part of her PhD dissertation.

Dr. Florinia E. Merca is the lead author’s major adviser. She was involved in the preparation of the manuscript.

Dr. Edralina P. Serrano is the lead author’s co-adviser. She was involved in management of the study and the preparation of the manuscript. The experiments were conducted in her laboratory. The study is part of her project funded by NIHHS-RDA.

Dr. Elda B. Esguerra is part of the lead author’s panel. She was also involved in the management of the study. The experiments were conducted in her laboratory. The study is part of her project funded by NIHHS-RDA.

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