Effects of 1-Methylcyclopropene and Hot Water Quarantine Treatment on Quality of "Keitt" Mangos

Panita Ngamchuachit, Diane M. Barrett, and Elizabeth J. Mitcham

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Abstract: The optimal 1-methylcyclopropene (1-MCP) treatment to slow ripening of whole "Keitt" mangos, either alone or in combination with hot water treatment (HWT) (prior to or post 1-MCP) was identified. USDA-APHIS mandates that HWT can be used for control of fruit flies, but this may affect fruit response to 1-MCP. Mangos were evaluated by repeated measurement of nondestructive firmness, peel color, and ethylene production on the same mango fruits during 2 wk of ripening at 20 °C after treatment. The magnitude of ethylene production increased as a result of both 1-MCP and HWT. With softer mangos (65 N), treatment with 1-MCP alone delayed fruit softening and extended the number of days to full-ripeness (25 N) from 5 d in untreated fruit to 11 d. For these riper fruit, application of 1-MCP prior to HWT extended the days to full-ripeness to 9 d compared with 7 d when 1-MCP was applied after HWT. With firmer mangos (80 N), 1-MCP treatments alone prolonged the days to full-ripeness to 13 d as compared to 11 d for the untreated fruit. There was no significant concentration effect on firmness retention among 1-MCP treatments (0.5, 1.0, or 10.0 μL/L). HWT resulted in a faster rate of fruit softening, taking only 7 d to reach full-ripeness. Combining 1-MCP with HWT reduced the rate of softening compared to HWT alone, resulting in 9 to 11 d to full-ripeness. Application of 1-MCP before HWT showed a greater ability to reduce the rate of fruit softening compared with 1-MCP treatment after HWT.

Keywords: *Mangifera indica* L., mango, 1-MCP, phytosanitary, quarantine

Practical Application: Application of 1-MCP alone or as a pretreatment prior to a hot water treatment required for quarantine may be a method for reducing softening of mangos shipped long distances. 1-MCP treatment delayed fruit softening and peel color changes, but hot water treatments accelerated softening. The application of 1-MCP treatment prior to hot water treatment reduced subsequent mango ripening, and the 1-MCP application has value for both domestic and imported mangos.

Introduction

Mangos (*Mangifera indica* L.) are one of the most popular and economically significant tropical fruits, and are widely distributed all over the world. In 2011, more than 39 million tons were produced worldwide. The United States is the world's leading importer of mangos, representing about 33% of the world's imported mangos in 2011 (FAO 2013). Mangos are imported to the United States throughout the year from various countries in Latin America. Loss of fruit firmness can interfere with the marketing of mangos by increasing their susceptibility to bruising and decay during shipping and storage. A reduction in fruit softening rates during shipping and storage would be beneficial, especially for distant markets.

1-Methylcyclopropene (1-MCP), an inhibitor of ethylene action, is marketed for use as a gas treatment on fresh fruit to delay fruit ripening and senescence. 1-MCP irreversibly binds to ethylene receptors in plant tissues, blocking the binding of ethylene and therefore the effects of ethylene on the tissues (Sisler and Serek 1997). Physiological responses of climacteric fruit to 1-MCP include altered ethylene production and respiration, prevented or delayed color changes, delayed softening, and altered or delayed development of volatile compounds (Watkins 2006). The use of 1-MCP on mangos has been reported to delay fruit softening, climacteric peak, rate of respiration, weight loss, and the increase in ascorbic acid content during mango fruit storage (Sivakumar and others 2011). However, other authors found that 1-MCP had no effect (Osuna-Garcia and others 2007) or in some cases, increased the incidence of stem-end rot (Hofman and others 2001). The effective 1-MCP concentration for prolonging the shelf life of mangos was reported as between 1 and 100 μL/L (Jiang and Joyce 2000). Lalel and others (2003) reported less effect of low concentrations such as 1 μL/L of 1-MCP on the aroma profiles of "Kensington Pride" mangos.

Hot water treatment (HWT) is the most common quarantine treatment option used by the mango industry to satisfy requirements of USDA-APHIS for treatment of most mangos exported to the United States from areas infested with fruit flies (Jacobi and others 2001). A previous study reported that hot water quarantine treatment reduced the efficacy of 1-MCP treatment on mango fruit (Osuna-Garcia and others 2007).

MS 20131452 Submitted 10/11/2013, Accepted 12/27/2013. *Authors Ngamchuachit is with Dept. of Food Technology, Chulalongkorn Univ., Bangkok, Thailand. Dept. of Food Science and Technology, Univ. of California, Davis, CA, U.S.A. Authors Barrett is with Dept. of Food Science and Technology, Univ. of California, Davis, CA, U.S.A. Authors Mitcham is with Dept. of Plant Sciences, Univ. of California, Davis, CA, U.S.A. Direct inquiries to author Ngamchuachit (E-mail: Panita.N@chula.ac.th).*

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Table 1–Significance of treatment and days of ripening on firmness, color, and maximum ethylene production for "Keitt" mangos in 2011 and 2012.

	Firmness (N)	Peel color		Maximum C_2H_4 production
		a^* value	Hue angle	($\mu L\ C_2H_4/kg/h$)
2011				
Treatment (T)	***	***	***	**
Days at 20 °C (D)	***	***	***	***
T × D	***	*	ns	*
2012				
Treatment (T)	***	***	***	***
Days at 20 °C (D)	***	***	***	***
T × D	***	***	***	***

ns = not significant.
*,**,*** significant at $P < 0.05$, 0.01, or 0.001, respectively.

The objectives of this study were to identify the optimal 1-MCP treatment for whole mango fruit to reduce the rate of fruit softening after harvest, and to further characterize the effect of the HWT on the efficacy of the 1-MCP treatment.

Materials and Methods

Plant material

"Keitt" mangos (10 count, mean fruit weight of 457 g) at ripening stage 2 (National Mango Board 2010) were purchased from a commercial packinghouse in Riverside, Calif., U.S.A., in October 2011 and September 2012 and transported to the Univ. of California, Davis, Calif., in an air-conditioned vehicle. The Natl. Mango Board's mango maturity and ripeness guide defines the S2 stage as having an orange color in the center of the mango flesh. These mangos had not been subjected to a quarantine treatment upon receipt. The fruits were visually sorted to eliminate damaged and defective fruits and nondestructively sorted using a compression test (described under Firmness section below) to obtain mangos with initial firmness of 60 to 70 N in 2011, and 75 to 85 N in 2012. Treatments were imposed within 1 d of harvest.

Treatments

In 2011, 270 mangos were randomly divided into 3 replicates of 5 treatment groups with 54 fruits per treatment (18 fruits per replicate). The 5 treatment groups consisted of mangos that were exposed to 1-MCP alone at 0, 0.5, or 1.0 μL/L, or 1-MCP at 1.0 μL/L prior to or post HWT.

In 2012, 378 mangos were randomly divided into 3 replicates of 7 treatment groups with 54 fruits per treatment (18 fruits per replicate). The 7 treatment groups consisted of mangos that were exposed to 1-MCP alone at 0, 0.5, 1.0, or 10.0 μL/L, or 1-MCP at 1.0 μL/L prior to or post-HWT, or HWT alone. For each replicate, 15 mangos were evaluated for skin color and compression firmness and 3 mangos were used for measurement of ethylene production. For the 1-MCP treatments, 18 fruits from each replicate were placed in 117.8 L sealed containers (3 containers in total per treatment) and were exposed to gaseous 1-MCP at 20 °C for 24 h. Untreated and HWT alone fruits were kept under similar conditions. The HWT was applied at 46 °C for 75 min following the USDA treatment schedule T102-a for rounded mango with fruit weight less than 500 g (USDA-APHIS 2012). The hot-water-treated mangos were air-dried at room temperature for 2 h. After treatment, mangos were ripened at 20 °C greater than 90% relative humidity (RH) until they reached full-ripeness (25 N). On the day prior to treatment and every 2 d during ripening at 20 °C, mango peel color (CIE $L^*a^*b^*$), firmness (compression test), and ethylene production were measured on the same fruit.

Flesh color

The peel color of 15 mangos was evaluated for each replicate every 2 d during storage. Individual fruits were marked on 2 opposite sides of the equatorial region in an area free of red blush, and color was measured at the same location each time. Color was measured in the CIE $L^*a^*b^*$ mode using a Minolta Colorimeter (model CR-300, Minolta Co., Ramsey, N.Y., U.S.A.), calibrated with a standard white plate. Peel color was expressed as a^* value (green to red).

Firmness

Compression firmness of mangos was measured nondestructively using a Texture Analyzer (Model TA.XT plus, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) equipped with a 5 kg load cell and using a test speed of 5 mm/s. During firmness measurements of whole mangos, an individual fruit was laid on 1 side, supported with an 8.5-cm-diameter aluminum cradle, manufactured at the Univ. of California, Davis. The force (N) required to compress the fruit was recorded when a 35-mm flat-tipped cylindrical probe reached 2.5 mm deformation on the equatorial region of the mango. The 15 mangos per replicate of each treatment were measured every 2 d during ripening until they reached full-ripeness, which was defined as 25 N.

Gas analysis

In 2011, the 3 mangos per replicate of each treatment were sealed together in a 9.46 L glass jar. In 2012, the 3 mangos per replicate of each treatment were sealed individually in 1.25 L polyvinyl chloride containers. The fruits were sealed for 1 to 2 h prior to gas sampling. The 10 mL headspace gas samples were collected with a plastic syringe. A gas chromatograph (Model 211, AGC Series 400; Hach-Carle Co., Colo., U.S.A.) with flame ionization detector (FID) and alumina column was used for ethylene measurement. Nitrogen was used as the carrier gas at a flow rate of 30 mL/min, and the injector port, detector port, and oven temperatures were set at 80 °C. Ethylene production was measured every 2 d during ripening using the same fruit for each treatment replicate.

Statistical analysis

The effects of each treatment on mango firmness, peel color, and maximum ethylene production were analyzed using analysis of variance performed on main effects and interactions for all treatments, and means were compared using Fisher's least squares difference (LSD) at $P < 0.05$ (SAS version 9.0, Cary, N.C., U.S.A.).

Results

Firmness

The mangos from both seasons were harvested mature at S2 stage (National Mango Board 2010). The mangos in 2011 were harvested and exposed to treatments at a more advanced ripeness stage, with approximately 65 N firmness compared to approximately 80 N firmness in 2012. Firmness decreased throughout ripening and there were differences in firmness among the various treatments (Table 1).

In 2011, untreated mangos softened rapidly and reached full-ripeness (25 N) within 5 d at 20 °C, whereas mango fruit treated with 1-MCP alone (0.5 or 1.0 μL/L) softened more slowly, reaching only 36.0 or 38.1 N after 5 d, respectively (Figure 1a). Mangos treated with 1-MCP (1.0 μL/L) prior to or post-HWT were intermediate in their rate of softening, reaching firmness of 30.2 or 27.3 N after 5 d at 20 °C, respectively. 1-MCP treatment alone extended the days at 20 °C to full-ripeness by 6 d for 0.5 and 1.0 μL/L 1-MCP, 4 d for 1.0 μL/L 1-MCP prior to HWT, and 2 d for 1.0 μL/L 1-MCP post-HWT (Table 2). 1-MCP treatment alone (0.5 or 1.0 μL/L) resulted in the greatest delay in mango fruit ripening as characterized by a significant delay in fruit softening.

In 2012, the effect of HWT alone was also investigated. The treatments had an effect on mango firmness (Table 1), with 1-MCP-treated fruit softening more slowly and HWT mangos softening more rapidly than untreated controls (Figure 1b). HWT fruit ripened fully (25 N) in 7 d as compared to 11 d for the untreated control (Table 2). Fruit treated with 1-MCP alone ripened in 13 d; however, when HWT was combined with 1-MCP, fruit softened more rapidly. No effect of 1-MCP concentration on firmness retention was detected.

Peel color

The changes in peel color of "Keitt" mango fruit were best described by the a^* value. Prior to ripening, mango peel had a moderate green color. In both years, the fruit peels of all treatments became less green (less negative CIE a^* value) during ripening at 20 °C (Table 1 and Figure 2). The "Keitt" mangos in 2011 were less green than the "Keitt" mangos used in 2012.

The specific treatment affected peel color changes during ripening in both years (Table 1). In 2011, the untreated control fruit showed a greater loss of the green peel color, whereas fruit treated with 1.0 μL/L 1-MCP maintained the greenest peel among the treatments (Figure 2a). In 2012, the fruit treated with HWT alone or in combination with 1-MCP showed the greatest loss of green peel color, with fruit treated with HWT alone showing the greatest color change (Figure 2b). Fruit treated with 1-MCP (0.5, 1.0,

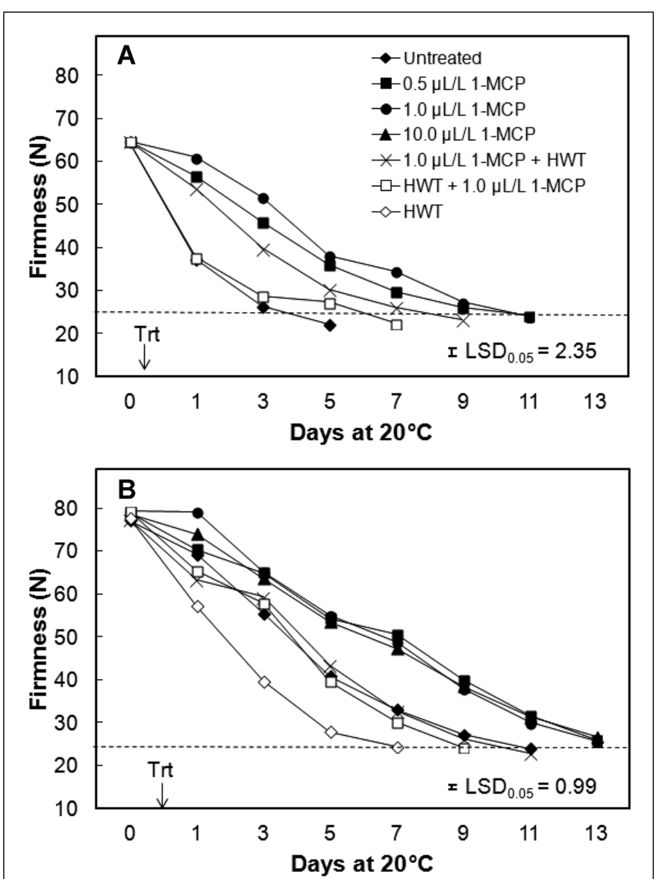

Figure 1–Changes in firmness (*N*) during ripening of "Keitt" mangos to 25N at 20 °C in 2011 (a) and 2012 (b) following treatment with 1-MCP alone (0.5, 1.0, and 10.0 μL/L), hot water alone (HWT), 1-MCP prior to or post-HWT (46 °C for 75 min), or no treatment. Values are mean of 45 observations. Some treatments were not included in 2011.

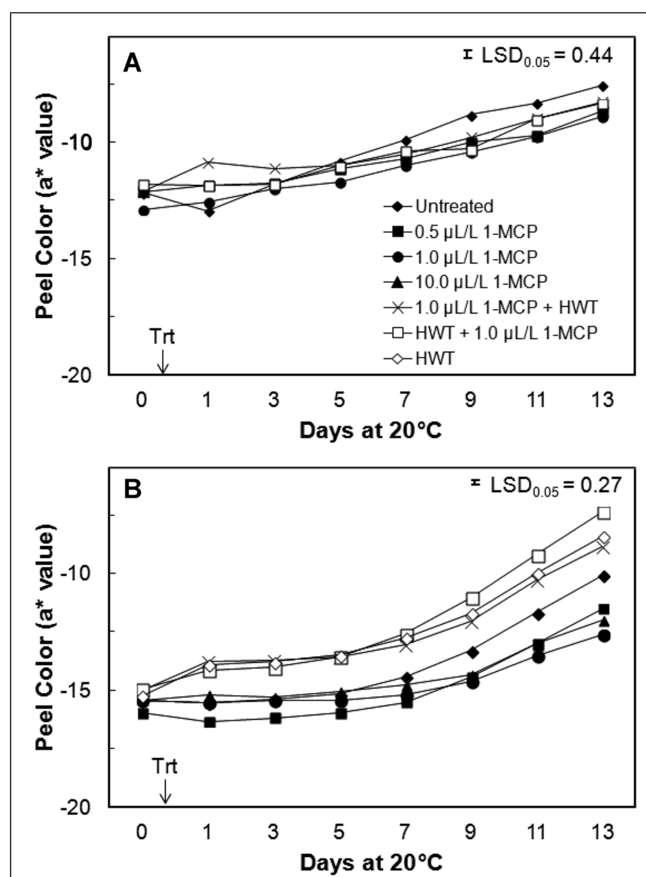

Figure 2–Changes in peel color (a^* value) during ripening of "Keitt" mangos to 25 N at 20 °C in 2011 (a) and 2012 (b) following treatment with 1-MCP alone (0.5, 1.0, and 10.0 μL/L), hot water alone (HWT), 1-MCP prior to or post-HWT (46 °C for 75 min), or no treatment. Values are mean of 45 observations. Some treatments were not included in 2011.

Table 2–Days to full-ripeness and days to peak and maximum C_2H_4 production for "Keitt" mangos treated with 1-MCP and/or hot water and ripened at 20 °C in 2011 and 2012.

Season	Days to full-ripeness	Days to peak C_2H_4	Maximum C_2H_4 production[A] (μL C_2H_4/kg/h)
2011			
Untreated	5	3	1.94 ± 0.42 b[B]
0.5 μL/L 1-MCP	11	3	2.25 ± 0.49 ab
1.0 μL/L 1-MCP	11	3	2.42 ± 0.18 ab
1.0 μL/L 1-MCP + HWT[C]	9	3	2.54 ± 0.16 a
HWT + 1.0 μL/L 1-MCP	7	3	2.34 ± 0.12 ab
2012			
Untreated	11	1	0.31 ± 0.02 de
0.5 μL/L 1-MCP	13	1	0.30 ± 0.02 e
1.0 μL/L 1-MCP	13	1	0.33 ± 0.01 d
10.0 μL/L 1-MCP	13	1	0.36 ± 0.03 c
1.0 μL/L 1-MCP + HWT	11	1	0.42 ± 0.01 ab
HWT + 1.0 μL/L 1-MCP	9	1	0.44 ± 0.02 a
HWT	7	1	0.40 ± 0.02 b

Mango fruits were treated with 1-MCP for 24 h at 20 °C and/or hot water.
[A]C_2H_4 production data are means ± S.D. of 3 replicates.
[B]In each year, values with the same letter were not significantly different ($P > 0.05$); [C]HWT = hot water treatment (46 °C for 75 min).

or 10.0 μL/L) showed less loss of peel green, and the control fruits were intermediate in peel color (Table 1 and Figure 2b).

Ethylene production

The patterns of ethylene production of "Keitt" mangos from all treatments and seasons were typical of climacteric fruit during ripening. Ethylene production was higher in 2011 than 2012 (Figure 3). The ethylene production of fruit from all treatments increased steadily at 20 °C and reached a maximum on day 3 (2011) and day 1 (2012) of storage, and then declined and remained lower (Figure 3). The treatments did not delay or accelerate the days to maximum ethylene production, but there was a treatment effect on the maximum C_2H_4 production.

In 2011, the maximum peak of ethylene production for the untreated control fruit was lower than the 1-MCP followed by HWT (Table 2 and Figure 3a). In 2012, mangos that were treated with HWT alone or HWT combined with 1-MCP treatment had higher ethylene production than 1-MCP treatment alone or untreated control fruit. Fruits treated with 1.0 μL/L 1-MCP after HWT had the highest peak in ethylene production, and the untreated control and 0.5 μL/L 1-MCP fruit produced the least ethylene (Table 2 and Figure 3b). Mangos treated with 10 μL/L 1-MCP had a higher peak in ethylene production than the untreated control fruits.

Discussion

"Keitt" mangos from both seasons were preclimacteric at harvest. Ethylene production was higher, mangos were softer, and peel color was less green in 2011 than in 2012, all of which indicate more advanced ripeness of the mangos tested in 2011. In general, 1-MCP effectively delayed ripening of "Keitt" mango compared to the untreated control as characterized by a delay in fruit softening, confirming previous findings (Jeong and others 2002, 2003; Alves and others 2004; Osuna-Garcia and others 2007; Wang and others 2009). In our study, similar results were found with both less ripe (80 N) and more advanced ripeness stages (65 N), that is, the effect of 1-MCP was greater when it was not combined with a HWT, in agreement with a previously published report (Osuna-Garcia and others 2007). Hot-water-treated mangos showed an accelerated rate of softening, potentially due to the breakdown of mesocarp cells from prolonged HWT (Jacobi and Gowanlok 1995) accompanied by an increase in β-galactosidase activity (Ketsa and others 1998), and loss of green peel color as compared to the untreated control fruit. Application of 1-MCP prior to HWT resulted in a significant reduction in the rate of firmness loss

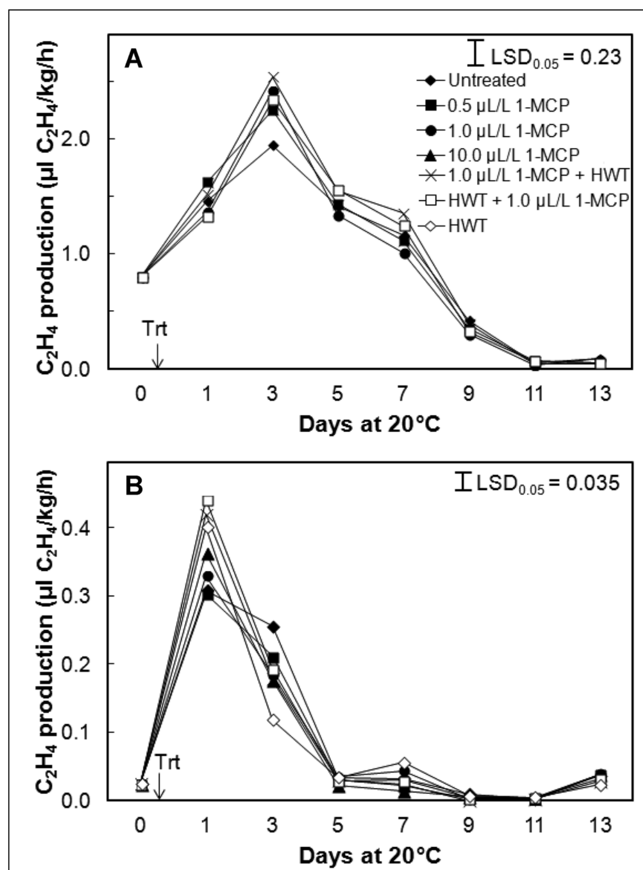

Figure 3–Changes in ethylene production (μL C_2H_4/ kg/h) during ripening of "Keitt" mangos to 25 N at 20 °C in 2011 (a) and 2012 (b) following treatment with 1-MCP alone (0.5, 1.0, and 10.0 μL/L), hot water alone (HWT), 1-MCP prior to or post-HWT (46 °C for 75 min), or no treatment. Values are mean of 3 observations. Some treatments were not included in 2011.

compared to fruit treated with hot water followed by 1-MCP. HWT resulted in the fastest softening rate in mangos, 1-MCP resulted in the slowest softening, and the combined treatment was intermediate in softening. The application of 1-MCP post-HWT showed less efficacy on the delay in fruit softening, which might be due to reduced penetration of the gaseous 1-MCP into the fruit due to melting of the peel cuticle during the HWT.

With the riper mangos harvested in 2011, although untreated fruit softened rapidly, the fruit pretreated with 1-MCP prior to HWT took 4 d longer to reach full-ripeness, as compared to the untreated control. These data indicate that 1-MCP treatment might mitigate the enhanced softening sometimes caused by the hot water quarantine treatment. The degree of temperature precision of our HWT was much lower than that of commercial HWT facilities, and this may account for the degree of enhanced softening observed in our study.

Delayed climacteric ethylene production has been reported as a result of the 1-MCP treatment for "Royal Zee" plum (Dong and others 2002), "Galia" melon (Ergun and others 2005), and "Nam Dok Mai" mango (Penchaiya and others 2006). However, in our study, the 1-MCP treatment had no effect in delaying the climacteric ethylene production of "Keitt" mango fruit, but slightly increased the magnitude of the ethylene peak compared with untreated control fruit. A similar effect was also shown in banana (Golding and others 1998), grapefruit (Mullins and others 2000), strawberry (Tian and others 2000), avocado (Jeong and others 2003; Hershkovitz and others 2005), and "Tainong" mango (Wang and others 2009) that might have been due to repression of the ethylene biosynthesis pathway's signaling mechanism, effectively shutting down the feedback system that modifies ethylene biosynthesis, resulting in increased ethylene biosynthesis (Mullins and others 2000). The high ethylene production measured in HWT mangos likely resulted from a response to heat stress (Mitcham and McDonald 1993).

Conclusions

In previous studies, application of 1-MCP to mango fruit with no HWT delayed fruit ripening at 20 °C. A reduction in the efficacy of 1-MCP on mango was found in HWT fruit. In the present study using "Keitt" mangos, application of 1-MCP treatment prior to hot water quarantine treatment showed promise for slowing subsequent mango ripening. Although treatment with 1-MCP prior to HWT did not slow ripening as much as 1-MCP alone, the treatment did delay fruit softening and peel color changes relative to HWT alone. Application of 1-MCP alone or as a pretreatment prior to a required HWT could be a method to reduce softening of mangos shipped long distances.

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References

Alves RE, Filgueiras HAC, da Silva Almeida A. 2004. Postharvest ripening of 'Tommy Atkins' mangoes on two maturation stages treated with 1-MCP. Acta Hortic 645:627–32.

Dong L, Lurie S, Zhou HW. 2002. Effect of 1-methylcyclopropene on ripening of 'Canino' apricots and 'Royal Zee' plums. Postharvest Biol Technol 24:135–45.

Ergun M, Jeong J, Huber DJ, Cantliffe DJ. 2005. Suppression of ripening and softening of 'Galia' melons by 1-methylcyclopropene applied at preripe or ripe stages of development. HortScience 40:170–5.

FAO. 2013. FAOSTAT. Available from: http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535#ancor. Accessed 2013 October 9.

Golding JB, Shearer D, Wyllie SG, McGlasson WB. 1998. Application of 1-MCP and propylene to identify ethylene dependent ripening processes in mature banana fruit. Postharvest Biol Technol 14:87–98.

Hershkovitz V, Saguy SI, Pesis E. 2005. Postharvest application of 1-MCP to improve the quality of various avocado cultivars. Postharvest Biol Technol 37:252–64.

Hofman PJ, Jobin-Décor M, Meiburg GF, Macnish AJ, Joyce DC. 2001. Ripening and quality responses of avocado, custard apple, mango and papaya fruit to 1-methylcyclopropene. Aust J Exp Agric 41:567–72.

Jacobi KK, Gowanlok D. 1995. Ultrastructural studies of 'Kensington' mango (*Mangifera indica* L.) heat injuries. HortScience 30(1):102–3.

Jacobi KK, MacRae EA, Hetherington SE. 2001. Postharvest heat disinfestation treatments of mango fruit. Sci Hortic 89(3):171–93.

Jeong H, Huber DJ, Sargent SA. 2003. Delay of avocado (*Persea americana*) fruit ripening by 1-methylcyclopropene and wax treatments. Postharvest Biol Technol 28:247–57.

Jeong J, Huber DJ, Sargent SA. 2002. Influence of 1-methylcyclopropene (1-MCP) on ripening and cell-wall matrix polysaccharides of avocado (*Persea americana*) fruit. Postharvest Biol Technol 25:241–56.

Jiang Y, Joyce DC. 2000. Effects of 1-methylcyclopropene alone and in combination with polyethylene bags on the postharvest life of mango fruit. Ann Appl Biol 137:321–7.

Ketsa S, Chidtragool S, Klein JD, Lurie S. 1998. Effect of heat treatment on changes in softening, pectic substances and activities of polygalacturonase, pectinesterase and β-galactosidase of ripening mango. J Plant Physiol 153:457–61.

Lalel HJD, Singh Z, Tan SC. 2003. Glycosidically-bound aroma volatile compounds in the skin and pulp of Kensington Pride mango fruit at different stages of maturity. Postharvest Biol Technol 29:205–18.

Mitcham EJ, McDonald RE. 1993. Effects of quarantine heat treatment on mango fruit physiology. Acta Hortic 343:361–6.

Mullins ED, McCollum TG, McDonald RE. 2000. Consequences on ethylene metabolism of inactivating the ethylene receptor sites in diseased non-climacteric fruit. Postharvest Biol Technol 19:155–64.

National Mango Board. 2010. Maturity and firmness guide. Available from: http://www.mango.org/sites/default/files/download/Mango%20Maturity%20and%20Ripeness%20Guide.pdf. Accessed 2012 October 25.

Osuna-Garcia JA, Caceres-Morales I, Gonzalez E. 2007. Effect of 1-methylcyclopropene (1-MCP) and hot water treatment on physiology and quality of 'Keitt' mangos. Revista Chapingo Serie Hortic 13(2):157–63.

Penchaiya P, Jansasithorn R, Kanlayanarat S. 2006. Effect of 1-MCP on physiological changes in mango 'Nam Dokmai'. Acta Hortic 712:717–22.

Sisler EC, Serek M. 1997. Inhibitors of ethylene responses in plants at the receptor level: recent developments. Physiol Plant 100:577–82.

Sivakumar D, Jiang Y, Yahia EM. 2011. Maintaining mango (*Mangifera indica* L.) fruit quality during the export chain. Food Res Intl 44:1254–63.

Tian MS, Prakash S, Elgar HJ, Young H, Burmeister DM, Ross GS. 2000. Responses of strawberry fruit to 1-methylcyclopropene (1-MCP) and ethylene. Plant Growth Regul 32:83–90.

USDA-APHIS. 2012. Plant protection and quarantine treatment manual, schedules T102-a. Available from: http://manuals.cphst.org/TIndex/getSchedule.cfm?scheduleName=T102-a. Accessed 2012 November 18.

Wang B, Wang J, Feng X, Lin L, Zhao Y, Jiang W. 2009. Effect of 1-MCP and exogenous ethylene on fruit ripening and antioxidants in stored mango. Plant Growth Regul 57:185–92.

Watkins CB. 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnol Adv 24:389–409.