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Effect of 1-methylcyclopropene (1-MCP) on softening of fresh-cut kiwifruit, mango and persimmon slices

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Abstract

Ethylene production is enhanced by wounding during fresh-cut processing and the accumulation of this gas within the packages of fresh-cut fruit can be detrimental to their quality and shelf-life. The effect of 1-methylcyclopropene (1-MCP), an ethylene action blocker, applied before or after processing, on the quality of fresh-cut kiwifruit, mangoes and persimmons was evaluated during storage at 5 °C. Fresh-cut 'Hayward' kiwifruit slices softened at a slower rate and their ethylene production rate was decreased in response to 1-MCP application (1 $\mu L L^{-1}$ for 6 h at 10 °C) either before or after processing. A 2-min dip in 0.09 M (1%, w/v) $CaCl_2$ synergistically increased the effect of 1-MCP on firmness retention and 1-MCP did not affect the color (L* value) of fresh-cut kiwifruit slices. Softening and browning (decreasing L* value) were delayed when 1-MCP was applied directly on fresh-cut 'Kent' and 'Keitt' mango slices. Respiration rate of mango slices was not influenced by 1-MCP whereas the ethylene production was affected only towards the end of their shelf-life. Fresh-cut 'Fuyu' persimmons treated with 1-MCP after processing presented higher ethylene production rate, slower softening rate and slower darkening of color (decrease in L* value), whereas the respiration rate was not affected.

Keywords: Color; Ethylene; Firmness; Quality; Respiration

1. Introduction

Ethylene has an undesirable effect on the quality of fresh-cut fruit. Its production is stimulated by physical actions used in the processing, and removal of ethylene from the storage environment may extend the shelf-life of fresh-cut fruit. Extended post-cutting life of fresh-cut kiwifruit, mangoes and persimmons has been reported when low temperatures, atmospheric modification, ethylene absorbent, calcium treatments and antibrowning agents were used (Abe and Watada, 1991; Wright and Kader, 1997; Agar et al., 1999; González-Aguilar et al., 2000).

1-Methylcyclopropene (1-MCP) is a recently developed inhibitor of ethylene action (Sisler and Serek, 1997). Ripening and senescence of intact and fresh-cut fruit have been delayed by 1-MCP action (Serek et al., 1995; Golding et al., 1998; Jiang et al., 1999; Kim et al., 2001; Pelayo et al., 2003; Aguayo et al., 2006; Vilas-Boas and Kader, 2006; Mao et al., 2007). 1-MCP is effective in delaying further ripening of partially ripe fresh banana (Pelayo et al., 2003), so it has potential commercial value to slow the changes associated with loss of quality and to extend the shelf-life of fresh-cut fruit, as shown for fresh-cut banana (Vilas-Boas and Kader, 2006). Exposure of fresh-cut apples to 1-MCP decreased ethylene production, respiration, softening, color change and synthesis of aroma compounds (Jiang and Joyce, 2002; Perera et al., 2003; Bai et al., 2004; Calderón-López et al., 2005). In pineapple, 1-MCP decreased respiration, browning and hydrolysis of ascorbic acid (Buda and Joyce, 2003). Ergun et al. (2006) reported that slices made from 1-MCP-treated papayas had double the shelf-life of slices made from untreated papayas.

The objectives of this work were to determine the effects of 1-MCP on changes in firmness, color, ethylene production, and respiration rate of fresh-cut kiwifruit, mangoes and persimmons.

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2. Material and methods

2.1. Material, slice preparation and storage

Partially ripe kiwifruit with flesh firmness of 15–20 N were obtained, kept overnight at 0 °C and processed at 10 °C. In experiment 1, kiwifruit ('Hayward' cultivar imported from Chile), purchased from a produce wholesaler in Sacramento, CA, were processed and the slices dipped in a 0.09 M (1%, w/v) $CaCl_2$ solution or water, for 2 min and treated with 1-MCP (1 μL L^{-1} for 6 h at 10 °C) and stored for 3 days at 10 °C. In experiment 2, kiwifruit ('Hayward' cultivar from California) obtained from a packinghouse in Winters, CA, were treated with 1-MCP (1 μL L^{-1} for 6 h at 10 °C) before or after processing and the slices stored for 7 days at 5 °C. In both experiments, fruit were peeled with a sharp knife and sliced with a meat slicer. Five slices were obtained from each fruit and 10 slices, from 10 different fruit, were used for each replicate. Before dipping in $CaCl_2$ solution or water, in the first experiment and 1-MCP treatment after processing, in the second experiment, slices were dipped in chlorinated water (1.3 mM NaOCl), drained and blotted dry with cheesecloth. After treatments, they were placed in 0.5-L jars, which were ventilated with humidified air at a flow rate of 1 mL s^{-1}.

Partially ripe 'Kent' and 'Keitt' mangoes with flesh firmness of 13–18 N and soluble solids content of 17.5–20 °B were obtained and kept overnight and processed at 10 °C. Fruit were dipped in chlorinated water (1.3 mM NaOCl), peeled and sliced into halves with a sharp knife before cutting into cubes (2 cm × 2 cm × 3 cm) with a sharp cutting device of stainless steel. Just after cutting, mango cubes were dipped in chlorinated water (1.3 mM NaOCl), drained, blotted with cheesecloth, submitted to different treatments and placed in 0.5-L jars that were ventilated with humidified air at a flow rate of 1 mL s^{-1}. In experiment 3, the cubes obtained from heat treated mangoes ('Kent' from Mexico) bought from a produce wholesaler in Sacramento, CA, were treated with 1-MCP (0.5 and 1 μL L^{-1} for 6 and 24 h at 10 °C) and stored for 4 days at 5 °C. In experiment 4, mangoes ('Keitt' from California) obtained from a packinghouse in Riverside, CA, were treated with 1-MCP (1 μL L^{-1} for 6 h at 10 °C) before or after processing, dipped, or not, in 0.090 M (1%, w/v) $CaCl_2$ + 0.056 M (1%, w/v) ascorbic acid +0.041 M (0.5%, w/v) cysteine solution and the cubes were stored for 9 days at 5 °C. Five cubes from each half were used and 10 cubes from 10 different fruit were used for each replicate.

Persimmons ('Fuyu' cultivar obtained from a packinghouse in Winters, CA and kept overnight at 0 °C) with flesh firmness of 50–60 N and soluble solids content of 14.1–14.3% were treated with 1-MCP (1 μL L^{-1} for 6 h at 10 °C) before or after processing and the fresh-cut wedges stored for 7 days at 5 °C. Stem ends of the fruit that were previously dipped in chlorinated water (1.3 mM NaOCl) were removed with a sharp knife and the remainders of the fruit, with peel, were cut into 12 wedges with a sharp wedge slicer of stainless steel. Ten wedges from 10 different fruit were used for each replicate, which were placed in 0.5-L jars ventilated with humidified air at a flow rate of 1 mL s^{-1}.

A summary of the experimental arrangements relative to the 5 experiments can be viewed in Table 1.

1-MCP (0.14 kg active ingredient per 100 kg commercial powder) was applied by injecting a measured volume of a stock dilution (1000 μL L^{-1}) into 10 L sealed glass jars. Concentrations of 1-MCP were calculated based on the free space volume of every jar and verified by flame ionization gas chromatography (model 211 Carle gas chromatograph, Anaheim, CA) using an isothermal separation (80 °C) on a 610 mm × 3.2 mm stainless steel column packed with 60–80 mesh Porapak Q (Supelco, Bellefonte, PA). Injector and detector temperatures were set at 80 °C and nitrogen at a flow rate of 0.42 mL s^{-1} was used as a carrier gas. Isobutylene was used as the standard gas to prepare the calibration curve. The source of 1-MCP was Agrofresh, Inc.

The CO_2 concentration in the jars of all experiments was maintained below 0.3 kPa at a flow rate of 1 mL s^{-1}. Ascorbic acid and calcium chloride were purchased from Sigma Chemical Co., St. Louis, MO. The source of cysteine HCl was Ajinomoto Co., Inc., Tokyo.

The processing of all fruit was carried out in a cold chamber at 10 °C, previously sanitized with chlorinated water and 70% ethanol. All facilities used to process the fruit were frequently washed and sanitized to ensure reasonably sterile conditions. The temperature of the chlorine solution and chemical dips used on fresh-cut fruit was 10 °C and the chlorine solution used on whole fruit was 20 °C. The pH of the chlorine solution was adjusted to 7.0.

Table 1
Resume of the experimental arrangements relative to five experiments developed in this work

Experiment	Treatments					
1—Kiwifruit	Control	MCP wf	MCP fc			
2—Kiwifruit	Control	Ca	MCP fc	Ca + MCP fc		
3—Mango	Control	0.5/6 h	1/6 h	0.5/24 h	1/24 h	
4—Mango	Control	Dip	MCP wf	MCP wf + dip	MCP fc	MCP fc + dip
5—Persimmon	Control	MCP wf	MCP fc			

MCP wf, 1-MCP (1 μL L^{-1} at 10 °C for 6 h) applied on whole fruit, before processing; MCP fc, 1-MCP (1 μL L^{-1} at 10 °C for 6 h) applied on fresh-cut slices; Ca, 0.090 M (1%, m/v) $CaCl_2$ dip for 2 min; 0.5/6 h, 0.5 μL L^{-1} 1-MCP applied for 6 h (at 10 °C); 1/6 h, 1 μL L^{-1} 1-MCP applied for 6 h; 0.5/24 h, 0.5 μL L^{-1} 1-MCP applied for 24 h; 1/24 h, 1 μL L^{-1} 1-MCP applied for 24 h; dip, 0.090 M (1%, m/v) $CaCl_2$ + 0.056 M (1%, m/v) ascorbic acid + 0.041 M (0.5%, m/v) cysteine.

2.2. Firmness

Firmness of slices was determined with a University of California Firmness Tester (Western Industrial Supply Co., San Francisco, CA) by measuring force required for a 3-mm probe to penetrate the cut surface on each of two sides to a depth of 5 mm.

2.3. Color

Color on two sides of each slice, cube or wedge was measured with a Minolta Chromameter (Model CR-300, Minolta, Ramsey, NJ) in the CIE L*a*b mode.

2.4. Ethylene and carbon dioxide production

A gas chromatograph (model 211 Carle Instruments, Anaheim, CA) with FID detector and alumina column was used to determine ethylene concentration and an infrared CO_2 analyzer (model PIR-2000R, Horiba Instruments, Irvine, CA) for CO_2 measurements in samples taken from the exit flow from each jar. Injector, detector and oven temperature of gas chromatograph were set at 80 °C and the carrier gas was nitrogen at 0.42 mL s^{-1}.

2.5. Statistical analysis

Three replicates per treatment and 10 slices, cubes or wedges per replicate were used in all experiments. Data were treated for multiple comparisons by analysis of variance with least significant difference (L.S.D.) between averages determined at 5% level.

3. Results and discussion

3.1. Fresh-cut kiwifruit

Exposure to 1-MCP (1 μL L^{-1} for 6 h at 10 °C) effectively slowed down the softening of fresh-cut kiwifruit slices stored for 7 days at 5 °C, on average, whether it was applied before or after processing (Table 2). When 1-MCP was applied directly to kiwifruit slices, it promoted effects similar to those of a 0.09 M (1%, w/v) $CaCl_2$ dip during 2 and 3 days of storage and a synergistic effect was observed on the third day at 10 °C (Table 3). Kim et al. (2001) found that 1-MCP reduced softening of intact kiwifruit and the effect tended to be concentration-dependent. Fresh-cut kiwifruit slices had slower rates of softening and a longer shelf-life when treated with 1% $CaCl_2$ or 2% Ca lactate and when the ethylene was removed from the storage atmosphere by using $KMnO_4$ (Agar et al., 1999). They found that kiwifruit slices treated with 1% $CaCl_2$ and then stored in ethylene-free air were firmer than those treated with either 1% $CaCl_2$ or ethylene scrubbing alone.

The color L* value of fresh-cut kiwifruit slices tended to decrease with time in storage (Tables 2 and 3). Application of 1-MCP before or after processing did not affect the L* value of the slices (Table 2), even when combined with $CaCl_2$ dip (Table 3). Agar et al. (1999) reported that the L* values

Table 2
Changes in firmness, L* value, ethylene and CO_2 production of fresh-cut kiwifruit stored at 5 °C

Treatment	Storage (days)					Mean
	0	1	2	4	7	
Firmness (N)						
Control	1.67 a		0.58 a	0.41 a	0.30 a	0.74 b
MCP wf	1.67 a		0.73 a	0.53 a	0.46 a	0.85 a
MCP fc	1.67 a		0.67 a	0.52 a	0.37 a	0.81 a
Mean	1.67 A		0.66 B	0.49 C	0.38 D	
Color (CIE L* value)						
Control	41.54 a		36.61 a	34.89 a	34.69 a	36.93 a
MCP wf	41.54 a		37.56 a	36.16 a	35.39 a	37.66 a
MCP fc	41.54 a		36.22 a	34.88 a	34.80 a	36.98 a
Mean	41.7 A		36.79 B	35.31 C	34.96 C	
Ethylene (ηg kg^{-1} s^{-1})						
Control		0.08 b	0.27 a	0.64 a	1.06 a	
MCP wf		0.07 b	0.23 a	0.32 b	0.45 b	
MCP fc		0.19 a	0.28 a	0.29 b	0.47 b	
CO_2 (μg kg^{-1} s^{-1})						
Control		3.02 a	2.40 b	2.69 a	3.32 a	
MCP wf		3.07 a	3.21 a	2.15 ab	2.62 b	
MCP fc		3.24 a	2.76 b	2.13 b	2.41 b	

Values for each parameter followed by the same lower-case letter within column (effect of treatment—mean or in each time) or capital letter within row (effect of time—mean) are not significantly different, $P < 0.05$. MCP wf =1-MCP (1 μL L^{-1} at 10 °C for 6 h) applied on whole fruit, before processing; MCP fc =1-MCP (1 μL L^{-1} at 10 °C for 6 h) applied on fresh-cut slices.

Table 3
Changes in firmness, L* value, ethylene and CO_2 production of fresh-cut kiwifruit stored at 10 °C

Treatment	Storage (days)				Mean
	0	1	2	3	
Firmness (N)					
Control	1.52 a	0.87 bc	0.61 c	0.55 c	
Ca	1.84 a	1.02 a	0.94 ab	0.89 b	
MCP	1.52 a	0.82 c	0.80 b	0.89 b	
Ca + MCP	1.84 a	0.96 ab	1.02 a	1.14 a	
L* value					
Control	44.06 a		37.58 a	35.99 a	39.21 a
Ca	41.40 a		38.31 a	37.50 a	39.07 a
MCP	44.06 a		37.49 a	36.51 a	39.36 a
Ca + MCP	41.40 a		38.89 a	37.05 a	39.11 a
Mean	42.73 A		38.07 B	36.76 C	
Ethylene ($\eta g\,kg^{-1}\,s^{-1}$)					
Control		0.47 a	1.15 a	2.00 a	
Ca		0.36 ab	1.14 a	1.98 a	
MCP		0.47 a	0.85 a	0.52 b	
Ca + MCP		0.33 b	0.98 a	0.62 b	
CO_2 ($\mu g\,kg^{-1}\,s^{-1}$)					
Control		8.54 a	5.18 a	4.88 a	6.20 ab
Ca		8.80 a	5.41 a	4.91 a	6.37 a
MCP		7.60 a	4.06 a	3.95 a	5.21 ab
Ca + MCP		6.41 a	4.55 a	3.55 a	4.83 b
Mean		7.84 A	4.80 B	4.32 B	

Values for each parameter followed by the same lower-case letter within column (effect of treatment—mean or in each time) or capital letter within row (effect of time—mean) are not significantly different, $P < 0.05$. Ca, 0.090 M (1%, w/v) $CaCl_2$ dip for 2 min; MCP, 1 $\mu L\,L^{-1}$ 1-MCP at 10 °C for 6 h.

Table 4
Changes in firmness, L* value, ethylene and CO_2 production of fresh-cut mangoes stored at 5 °C

Treatment	Storage (days)			Mean
	0	2	4	
Firmness (N)				
Control	2.70 a	1.25 a	1.39 a	1.78 b
0.5/6 h	2.70 a	1.76 a	1.72 a	2.06 ab
1/6 h	2.70 a	2.06 a	1.50 a	2.09 a
0.5/24 h	2.70 a	1.66 a	1.27 a	1.88 ab
1/24 h	2.70 a	1.71 a	1.35 a	1.92 ab
Mean	2.70 A	1.69 B	1.45 C	
Color (CIE L* value)				
Control	68.81 a	59.18 a	56.29 a	61.43 ab
0.5/6 h	68.81 a	58.89 a	56.35 a	61.35 ab
1/6 h	68.81 a	59.93 a	56.83 a	61.86 a
0.5/24 h	68.81 a	58.43 a	55.55 a	60.93 ab
1/24 h	68.81 a	55.62 a	54.84 a	59.76 b
Mean	68.81 A	58.41 B	55.98 C	
Ethylene ($\eta g\,kg^{-1}\,s^{-1}$)				
Control		5.43 ab	37.78 a	
0.5/6 h		6.03 ab	15.74 b	
1/6 h		5.12 ab	16.27 b	
0.5/24 h		4.22 b	14.43 b	
1/24 h		7.84 a	18.53 ab	
CO_2 ($\mu g\,kg^{-1}\,s^{-1}$)				
Control		8.13 a	7.54 a	7.84 a
0.5/6 h		9.08 a	6.19 a	7.63 a
1/6 h		6.19 a	4.77 a	5.48 a
0.5/24 h		7.42 a	5.66 a	6.54 a
1/24 h		8.31 a	6.13 a	7.22 a
Mean		7.83 A	6.06 A	

Values for each parameter followed by the same lower-case letter within column (effect of treatment—mean or in each time) or capital letter within row (effect of time—mean) are not significantly different, $P < 0.05$. 0.5/6 h, 0.5 $\mu L\,L^{-1}$ 1-MCP applied for 6 h (at 10 °C); 1/6 h, 1 $\mu L\,L^{-1}$ 1-MCP applied for 6 h; 0.5/24 h, 0.5 $\mu L\,L^{-1}$ 1-MCP applied for 24 h; 1/24 h, 1 $\mu L\,L^{-1}$ 1-MCP applied for 24 h.

decreased less rapidly in Ca-treated slices than in untreated slices of fresh-cut kiwifruit.

Kiwifruit are extremely sensitive to ethylene and soften quickly when exposed to as low as 0.1 $\mu L\,L^{-1}$ ethylene (Crisosto et al., 2000). Thus, ethylene concentration in the storage or package must be kept below 0.1 $\mu L\,L^{-1}$ to avoid undesirable softening of intact or fresh-cut kiwifruit. Exposure to 1-MCP decreased ethylene production of the slices after 2 days of storage regardless of the time of application (Tables 2 and 3). Kim et al. (2001) found that 1-MCP reduced ethylene production and fruit softening in intact kiwifruit. Charcoal with palladium chloride was effective in absorbing most of the endogenously produced ethylene during storage of kiwifruit slices (Abe and Watada, 1991).

Application of 1-MCP before or after processing reduced respiration rate of fresh-cut kiwifruit slices kept for 4 days or longer at 5 °C (Table 2). However, it did not influence the respiration rate of fresh-cut kiwifruit slices stored for 3 days at 10 °C, with or without $CaCl_2$ dip, when applied directly on slices (after processing) (Table 3). In contrast, Abe and Watada (1991) reported that the ethylene absorbent (charcoal with palladium chloride) decreased the respiration rate of fresh-cut kiwifruit slices stored at 20 °C for 3 days.

3.2. Fresh-cut mango

Fresh-cut mangoes ('Kent' cultivar from Mexico) that were treated with 1-MCP at 1 $\mu L\,L^{-1}$ for 6 h at 10 °C had the best quality in terms of firmness retention during storage at 10 °C (Table 4). Neither chemical dip nor 1-MCP applied on intact fruit (before processing) affected the firmness of fresh-cut mangoes stored at 5 °C. However, when applied directly to the slices, 1-MCP effectively delayed the softening of fresh-cut mangoes for 9 days (Table 5).

Browning is a limiting factor in the marketing of fresh-cut mangoes; color L* value of mango slices decreased (darkening increased) during storage for 4 days at 5 °C (Tables 4 and 5). Different exposure times and concentrations of 1-MCP applied to slices did not affect the color L* value of fresh-cut 'Kent' mangoes in comparison with control slices (Table 4). The initial L* value was 68.81 in this experiment. In contrast, color changes of fresh-cut 'Keitt' mango slices

Table 5
Changes in firmness, L* value, ethylene and CO_2 production of fresh-cut mangoes stored at 5 °C

Treatment	Storage (days)				Mean
	0	3	6	9	
Firmness					
Control	1.56 a	1.23 b	1.46 c	1.06 c	
Dip	1.56 a	1.58 ab	1.74 bc	1.39 bc	
MCP wf	1.56 a	1.58 ab	1.47 c	1.26 bc	
MCP wf + dip	1.56 a	1.79 a	1.61 bc	1.53 ab	
MCP fc	1.56 a	1.95 a	2.14 a	1.64 ab	
MCP fc + dip	1.56 a	1.65 a	1.96 ab	1.79 a	
Color (CIE L* value)					
Control	74.17 a	66.19 c	63.72 d	63.02 c	
Dip	74.17 a	72.12 a	72.60 a	68.77 ab	
MCP wf	74.17 a	69.01 b	64.91 cd	65.31 bc	
MCP wf + dip	74.17 a	70.12 ab	67.69 bc	71.51 a	
MCP fc	74.17 a	71.86 a	72.06 a	70.34 a	
MCP fc + dip	74.17 a	70.67 ab	70.90 ab	72.52 a	
Ethylene ($\eta g\,kg^{-1}\,s^{-1}$)					
Control		19.37 b	15.91 a	43.59 a	
Dip		51.33 a	21.91 a	36.93 ab	
MCP wf		17.13 b	16.01 a	22.54 b	
MCP wf + dip		20.16 b	17.92 a	19.60 b	
MCP fc		17.13 b	17.79 a	19.11 b	
MCP fc + dip		21.74 b	24.64 a	20.29 b	
CO_2 ($\mu g\,kg^{-1}\,s^{-1}$)					
Control		3.09 a	3.09 a	2.10 a	2.76 a
Dip		1.06 a	1.63 a	2.69 a	1.79 b
MCP wf		2.71 a	1.48 a	2.18 a	2.12 ab
MCP wf + dip		1.56 a	1.75 a	2.26 a	1.86 b
MCP fc		2.71 a	2.00 a	2.53 a	2.41 ab
MCP fc + dip		1.88 a	2.07 a	2.07 a	2.01 ab
Mean		2.17 A	2.00 A	2.31 A	

Values for each parameter followed by the same lower-case letter within column (effect of treatment—mean or in each time) or capital letter within row (effect of time—mean) are not significantly different, $P < 0.05$. Dip, 0.090 M (1%, m/v) $CaCl_2$ + 0.056 M (1%, m/v) ascorbic acid + 0.041 M (0.5%, m/v) cysteine; MCP wf, 1-MCP (1 $\mu L\,L^{-1}$ at 10 °C for 6 h) applied on whole fruit, before processing; MCP fc, 1-MCP (1 $\mu L\,L^{-1}$ at 10 °C for 6 h) applied on fresh-cut slices.

with an initial L* value of 74.17 were influenced by 1-MCP and chemical dip treatments. This observation may be associated with both different cultivars and different initial L* values. Chemical dip and 1-MCP applied directly to fresh-cut slices delayed their color darkening (decrease in L* value) during 9 days of storage at 5 °C (Table 3). Similarly, González-Aguilar et al. (2000) showed the efficiency of a chemical dip on the visual quality of fresh-cut mangoes. They reported that fresh-cut mango slices treated with the combination of D-isoascorbic acid, 4-hexylresorcinol and potassium sorbate and stored at 10 °C for 14 days resulted in the best maintenance of color L* value, visual appearance, and fewer symptoms of browning and decay.

Application of 1-MCP at 0.5 or 1 $\mu L\,L^{-1}$ for 6 h or at 0.5 $\mu L\,L^{-1}$ for 24 h decreased the ethylene production by fresh-cut 'Kent' mango slices stored at 5 °C only on the fourth day of storage in comparison with control slices (Table 4). That decrease was only observed on the 9th day of storage of 1-MCP-treated fresh-cut 'Keitt' mango slices stored at 5 °C (Table 5).

Respiration rate of mango slices was not influenced by 1-MCP treatments, but the chemical dip decreased it (Tables 4 and 5).

3.3. Fresh-cut persimmon

Treatment with 1-MCP was effective in preventing the softening of fresh-cut 'Fuyu'persimmons stored for 7 days at 5 °C only when applied on intact fruit before processing (Table 6).

Color L* value declined rapidly after processing of persimmons. Color L* value of fresh-cut persimmons wedges treated with 1-MCP (before processing) was higher than L* value of non-treated or 1-MCP treated slices after processing (Table 6).

Ethylene production by slices from 1-MCP-treated persimmons (before processing) was higher than that of control slices, averaged over the storage period; ethylene production rate by 1-MCP-treated slices was similar to control slices (Table 6). Similarly, 1-MCP has been shown to increase ethy-

Table 6
Changes in firmness, L* value, ethylene and CO_2 production of fresh-cut persimmons stored at 5 °C

Treatment	Storage (days)						Mean
	0	1	2	3	4	7	
Firmness (N)							
Control	8.24 a		7.04 b		6.92 b	7.14 b	
MCP wf	8.24 a		7.93 a		7.92 a	7.72 a	
MCP fc	8.24 a		6.83 b		7.53 ab	7.12 b	
Color (CIE L* value)							
Control	67.07 a		61.00 a		61.08 a	59.50 a	62.16 b
MCP wf	67.07 a		62.33 a		62.42 a	61.93 a	63.44 a
MCP fc	67.07 a		60.98 a		60.93 a	60.47 a	62.36 b
Mean	67.07 A		61.44 B		61.47 B	60.63 B	
Ethylene ($\eta g\, kg^{-1}\, s^{-1}$)							
Control		0.025 a	0.022 a	0.057 a	0.065 a	0.228 a	0.080 b
MCP wf		0.038 a	0.019 a	0.063 a	0.101 a	0.353 a	0.115 a
MCP fc		0.036 a	0.021 a	0.058 a	0.081 a	0.275 a	0.094 ab
Mean		0.033CD	0.021 D	0.059BC	0.082 B	0.286 A	
CO_2 ($\mu g\, kg^{-1}\, s^{-1}$)							
Control		0.74 a	0.59 a	0.92 a	0.92 a	1.29 a	0.89 a
MCP wf		0.70 a	0.49 a	0.97 a	0.79 a	1.19 a	0.83 a
MCP fc		0.50 a	0.55 a	0.82 a	0.91 a	1.12 a	0.78 a
Mean		0.65 C	0.54 C	0.90 B	0.87 B	1.20 A	

Values for each parameter followed by the same lower-case letter within column (effect of treatment—mean or in each time) or capital letter within row (effect of time—mean) are not significantly different, $P < 0.05$. MCP wf, 1-MCP (1 $\mu L\, L^{-1}$ at 10 °C for 6 h) applied on whole fruit, before processing; MCP fc, 1-MCP (1 $\mu L\, L^{-1}$ at 10 °C for 6 h) applied on fresh-cut slices.

lene production by fresh bananas (Golding et al., 1998) and pineapples (Selvarajah et al., 2001).

Application of 1-MCP either before or after processing did not affect the respiration rate of fresh-cut persimmons stored for 7 days at 5 °C (Table 6), similar to the responses of mangoes reported above. Respiration rates increased with time in storage, however.

4. Conclusions

Exposing partially ripe fruit to 1-MCP before cutting or after cutting may be a useful supplement to proper temperature and relative humidity management and chemical dips for maintaining quality of fresh-cut fruit products.

Softening of fresh-cut kiwifruit slices was delayed and ethylene production decreased by 1-MCP whether it was applied before or after processing. A 2-min $CaCl_2$ dip synergistically increased the efficacy of 1-MCP on firmness retention. Exposure to 1-MCP did not affect the darkening (as indicated by color L* value) of fresh-cut kiwifruit slices.

1-MCP applied directly on mango slices delayed their softening and darkening (decrease in L* value). Respiration rate was not influenced by 1-MCP whereas the ethylene production rate was affected only during the latter part of their shelf-life.

Softening and darkening (decrease in L* value) were retarded whereas ethylene production was enhanced when fresh-cut persimmons were treated with 1-MCP before processing. 1-MCP did not affect the respiration rate of fresh-cut persimmons.

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