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Variability in responses of partially ripe bananas to 1-methylcyclopropene

Clara Pelayo [a], Eduardo V. de B. Vilas-Boas [b], Mohamed Benichou [c], Adel A. Kader [d,*]

[a] *Departamento de Biotecnología, Universidad Autónoma Metropolitana-Iztapalapa, C.P. 09340, Mexico 2, DF, Mexico*
[b] *Departamento de Ciência dos Alimentos, Universidade Federal de Lavras, Lavras MG 37200-000, Brazil*
[c] *Department of Biology, Cadi Ayyad University, Marrakech 2390, Morocco*
[d] *Department of Pomology, University of California, One Shields Avenue, Davis, CA 95616, USA*

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Abstract

The effect of 1-methylcyclopropene (1-MCP) was evaluated on bananas at intermediate stages of ripeness after 36–48 h of having been commercially treated with ethylene. Several conditions for the application of 1-MCP including concentrations (100, 300 and 1000 nl l^{-1}), temperatures (14 and 20 °C) and durations of exposure (6, 12 and 24 h) were studied. In some experiments, bananas at ripeness stage 3 or 4 that were treated with 1000 nl l^{-1} 1-MCP at 20 °C for 6 or 24 h had higher ethylene production rates but respiration rates were reduced and changes in skin color and flesh firmness were delayed without negative impacts on the qualitative or quantitative aroma composition of the fruit. However, similar 1-MCP treatments were much less effective in retarding ripening of stage 3 or 4 bananas in subsequent experiments. We conclude that, under the conditions tested in this study, the efficacy of 1-MCP in delaying ripening of partially ripened bananas is too inconsistent for commercial application.

Keywords: ACC oxidase; ACC synthase; Aroma compounds; Color; Ethylene; Firmness; Respiration

1. Introduction

The ability of 1-methylcyclopropene (1-MCP) to delay ripening of mature-green, pre-climacteric bananas has been widely demonstrated (Sisler and Serek, 1997; Golding et al., 1998; Joyce et al., 1999) as well as the time–concentration–temperature dependence of this response (Yueming et al., 1999; Macnish et al., 2000). However, the reported efficacy of 1-MCP in these studies was quite variable. Harris et al. (2000) hypothesized that there was a significant interaction

* Corresponding author. Tel.: +1-530-752-0909; fax: +1-530-752-8502
E-mail address: aakader@ucdavis.edu (A.A. Kader).

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between the effectiveness of 1-MCP and the maturity of bananas; they found that 500 nl l^{-1} of 1-MCP at 20 °C for 24 h was more effective in delaying ripening as maturity progressed from 71 to 156–173 days after bunch emergence, although the absolute time for bananas to ripen decreased from 40 to 28 days, respectively, at 20 °C in a continuous air flow containing 0.1 μl l^{-1} of ethylene.

Commercially, once bananas are induced to ripen with ethylene, their marketing life is only about 3–5 days depending on ethylene treatment conditions and holding temperature after treatment. A method to slow down the ethylene-induced ripening process has economical significance for distribution centers and supermarkets. Cooling to 14 °C and modified atmosphere packaging (MAP) has been shown to be a promising procedure for this purpose (Gorny and Kader, personal communication), but bananas have to be repacked after the ethylene treatment into the polymeric film within which the appropriate MA will be established. Fumigation with 1-MCP seems to be a more convenient method since fruit repacking would not be required. The number of studies dealing with the effect of 1-MCP on retarding ripening of partially ripe bananas is limited (Joyce et al., 1999; Yueming et al., 1999) and no studies have been reported about the effect of 1-MCP on specific stages of ripeness of bananas commercially treated with ethylene. Joyce et al. (1999) found that banana ripening induced by propylene, an ethylene analog, can be delayed by exposure to 15 μl l^{-1} of 1-MCP at 20 °C for 12 h. However, the 1-MCP treatment was less effective as propylene-induced ripening progressed, although it was able to maintain the eating-ripe condition of fruits for a longer time than the control treatment. Similarly, Yueming et al. (1999) found that 1-MCP (in a concentration range 0.01–10 μl·l^{-1} at 20 °C for 12 h) applied after 1 day of ethylene treatment slowed down the ripening of bananas, but it was ineffective when applied 3 or 5 days after ethylene treatment.

The purpose of this study was to evaluate the efficacy of 1-MCP on ripening associated changes of bananas at selected stages of ripeness after the commercial application of ethylene.

2. Materials and methods

2.1. Experimental setup

Fruit were obtained from a wholesale produce distributor in Sacramento, CA. Bananas were sorted to eliminate the damaged fruit and to obtain the samples of uniform ripeness according to the standard banana ripening color chart. Three replicates of three clusters, containing three to four fingers per cluster, were used per treatment in all experiments. In experiment 1, 100, 300 or 1000 nl l^{-1} 1-MCP was applied on stage 3 bananas for 24 h at 20 °C. In experiment 2, stages 3–4 bananas were fumigated with 1000 nl l^{-1} 1-MCP at 20 °C for 6 or 24 h. Treatments of stage 4 bananas with 1000 nl l^{-1} 1-MCP at 14 °C were for 6 h in experiment 3 and 12 and 24 h in experiment 4. In experiment 5, stages 2, 3 and 4 bananas were subjected to 1000 nl l^{-1} 1-MCP for 24 h at 20 °C. Before 1-MCP was applied, fruit were equilibrated to the indicated temperature for every treatment. In all experiments, 1-MCP was applied by injecting a measured volume of a stock dilution 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 (Carle gas chromatograph, Model 211; EG & E Chandler Engineering, Tulsa, OK) using an isothermal separation (80 °C) on a 610 × 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 25 ml min^{-1} was used as a carrier gas. Isobutylene was used as the standard gas to prepare the calibration curve. After 1-MCP treatments, fruit were ventilated and kept in sealed glass jars with a continuous flow rate of air (free of ethylene) to maintain > 90% relative humidity and prevent CO_2 accumulation above 0.2%. Fruit in glass jars were kept at 20 °C until they reached ripeness stage 7.

2.2. Respiration and ethylene production rates

Three samples of 10 and 1 ml withdrawn daily from the headspace of every jar kept at 20 °C were used to analyze carbon dioxide and ethylene

production, respectively. Carbon dioxide was quantified by a Horiba Infrared Gas Analyzer, Model PIR-2000R (Horiba Instruments, Inc., Irvine, CA) and ethylene by a gas chromatograph (EG & E Chandler Engineering) equipped with a flame ionization detector and a packed alumina column. Injector, detector and oven temperature were set at 80 °C and the carrier gas was nitrogen at 25 ml min^{-1}. Based on areas of standard gases, concentrations of carbon dioxide and ethylene were calculated.

2.3. Color and firmness

Ten fingers per replicate were used to evaluate external skin color visually by the standard banana color chart (von Loesecke, 1950) or objectively, on opposite sides of every fruit, by a Minolta Chroma meter, Model CR-300 (Minolta, Ramsey, NJ). Color space a^* and b^* parameters were used to calculate the hue angle ($h = \arctan(b^*/a^*)$). Cross-sections from the middle part of the same fruit were used to measure flesh firmness by a University of California Firmness Tester (Western Industrial Supply, San Francisco, CA) fitted with an 8 or a 3 mm probe. The remaining cross-sections of fruit were frozen in liquid nitrogen, homogenized in a blender in the presence of liquid nitrogen to obtain a fine powder and stored at −80 °C until the activity of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase and the concentrations of aroma compounds were analyzed.

2.4. ACC synthase and ACC oxidase activities

Samples of banana powder were used to measure the activities of ACC synthase and ACC oxidase according to the methods previously described by Gorny and Kader (1996). The protein content was measured by the Bradford (1976) method by using the Bio-Rad reagent and bovine serum albumin as standard.

2.5. Aroma compounds

Frozen banana powder (0.5 g) was placed in a crimp-seal 16 ml vial. To avoid the generation of artifacts and limit changes in aroma compounds by enzymatic and chemical reactions, immediately after the powder was thawed at room temperature or before thawing was completed, 4.5 ml of a NaOH + EDTA solution was added to obtain a final pH of 6.2 and a 50 mM concentration of the chelating agent. To facilitate the release of aroma compounds, 1.5 g of NaCl was also added to every sample. Vials were sealed with a black Viton septum and 20 mm crimp caps, agitated for 1 min and analyzed by a headspace-solid phase microextraction (SPME) technique using a GC–mass spectrometer. A Varian 8200 cx autosampler (Walnut Creek, CA) mounted to a HP 5890 GC (Avondale, PA) paired with a HP5971 mass selective detector (with an electronic upgrade to a Model 5972) was the analytical system. This system was operated by HP MSD CHEMSTATION software. The GC oven was fitted with a 60 m × 0.32 mm ID and 1 μm film thickness DB-Wax capillary column (J&W Scientific, Folsom, CA). The temperature program was 50 °C held for 1 min, then increased to 110 °C at a 5 °C min^{-1} and to a 180 °C at 20 °C min^{-1} and finally held for 9 min. The injector temperature was held at 200 °C. The autosampler was fitted with a 65 μm Carbowax Divinylbenzene SPME fiber (Supelco, Bellefonte, PA). The autosampler was programmed for an 11 min cycle; 10 min adsorption time for sampling the headspace and 1 min for desorption in the GC injector. Headspace samplings were done at 25–30 °C. Identification of aroma compounds was initially accomplished by matching mass spectra with library values. Confirmation of the identity and quantification of the major volatiles were performed by trapping the volatiles from the headspace of standard aqueous solutions, containing 280 nl l^{-1} of 4-heptanone as internal standard, by the SPME fiber under the same conditions as those used for the banana flesh samples and by comparing areas with those of analytes. When identification of aroma compounds was only accomplished by matching mass spectra with library values, quantification was carried out by comparing peak areas of analytes to that of 4-heptanone added at 280 nl l^{-1} as internal standard to the banana sample.

2.6. Statistical analysis

SAS system version 7.0 (SAS Institute, Inc., Cary, NC) was used to perform analysis of variance and obtain LSD (5%) values of each of the main effects.

3. Results and discussion

3.1. Experiments 1 and 2

Exposure to 1-MCP delayed changes in skin color and flesh softening of bananas and the magnitude of this effect was dependent on concentration, but not on duration of exposure. A decrease in hue angle (h), representing a change in peel color from green to yellow, was observed in both control and 1-MCP-treated bananas kept at 20 °C, but a slower rate of this decrease in h value was evident only in 300 and 1000 nl l^{-1} 1-MCP-treated fruit without significant differences between these two concentrations (Fig. 1A). Fruit exposed to 1000 nl l^{-1} 1-MCP for 6 or 24 h did not show differences in skin color (h-values), but significant differences were found between control and 1-MCP-treated fruit (Fig. 1B).

Similarly, a difference in flesh firmness between control and 1000 nl l^{-1} 1-MCP-treated bananas was observed (Fig. 2A) and no significant differences in flesh firmness between fruit exposed to 1000 nl l^{-1} 1-MCP for 6 or 24 h were found (Fig. 2B).

Changes in respiration rate at 20 °C were similar in both control and 1000 nl l^{-1} 1-MCP-treated bananas. However, the rate of respiration was lower in 1-MCP-treated bananas than in control fruit (Fig. 3A). In contrast, ethylene production was higher in 1000 nl l^{-1} 1-MCP-treated than in control fruit (Fig. 3B). Similar results were reported by Golding et al. (1999) who speculated that 1-MCP may block the normal feedback regulation of ethylene production and presumably the transcription of ACC synthase may be enhanced or the malonylation of its substrate ACC may be prevented. An increase in

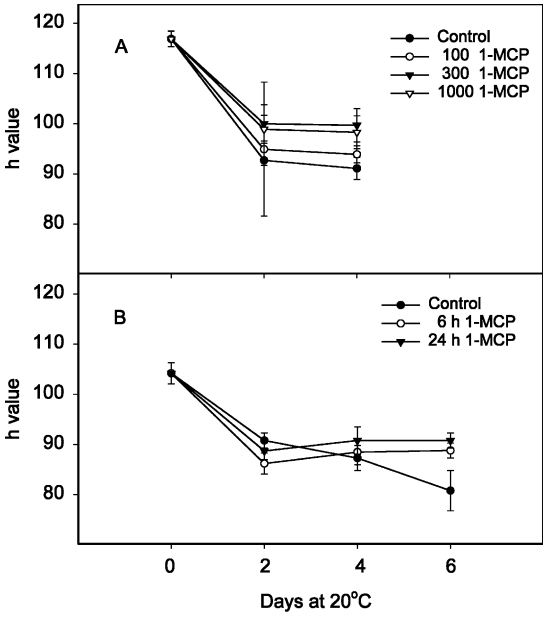

Fig. 1. Skin color of bananas (means of h-values ± SD) treated at 20 °C with different concentrations (nl l^{-1}) of 1-MCP for 24 h (A) and at 1000 nl l^{-1} for 6 or 24 h (B) and stored at 20 °C.

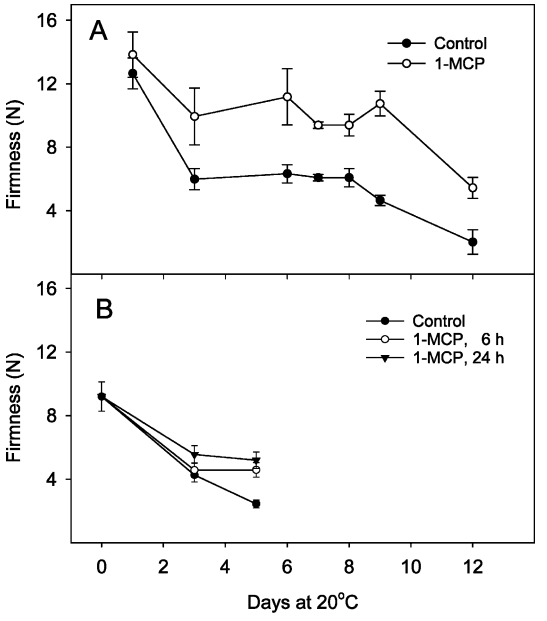

Fig. 2. Flesh firmness (means ± SD) of bananas treated with 1000 nl l^{-1} 1-MCP at 20 °C for 24 h (A) and for 6 or 24 h (B) and stored at 20 °C. Firmness was measured with an 8 mm probe.

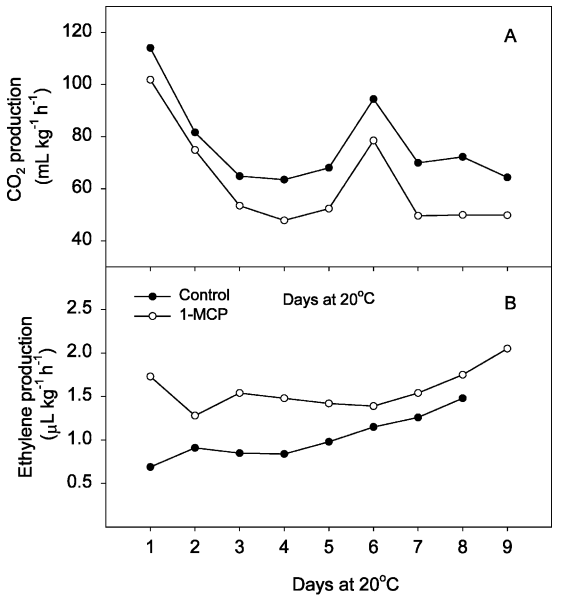

Fig. 3. Respiration rate (A) and ethylene production (B) of bananas treated with 1000 nl l^{-1} 1-MCP at 20 °C for 24 h and stored at 20 °C.

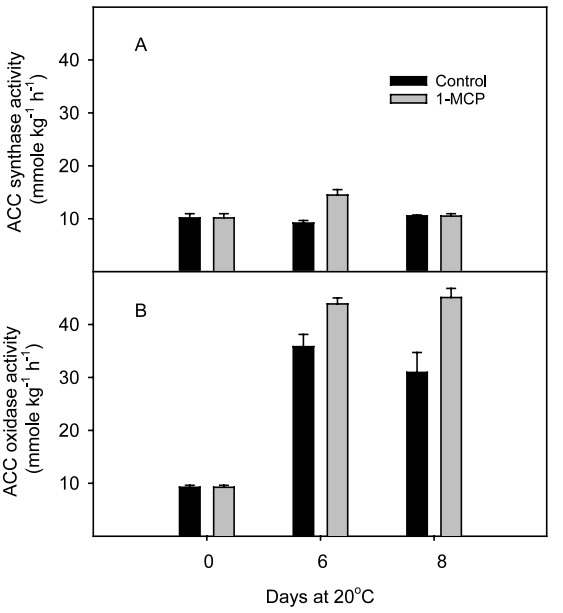

Fig. 4. Activities of ACC synthase (A) and ACC oxidase (B) (means ± SD) of bananas treated with 1000 nl l^{-1} 1-MCP at 20 °C for 24 h and stored at 20 °C.

the activity of ACC synthase in 1-MCP-treated bananas was observed only on day 6 (Fig. 4A) probably due to the fact that this enzyme has a rapid turnover rate (Kim and Yang, 1992). An increase in the activity of ACC oxidase in control and to a greater extent in bananas treated with 1000 nl l^{-1} 1-MCP was observed during storage at 20 °C (Fig. 4B). Moya-León and John (1994) reported an increase in the in vivo ACC oxidase activity in both peel and pulp of bananas up to 5 days at 20 °C after being treated with 60 µl l^{-1} ethylene.

Qualitatively, the only aroma compounds detected in bananas at stage 3 of ripeness before the 1-MCP treatment were the aldehyde(E) 2-nonenal, which is present in high levels in immature fruit, and the C_6 aldehydes hexanal and (E) 2-hexenal, which are important constituents of climacteric and post-climacteric bananas (Tressl and Drawert, 1973). These compounds contribute to the grassy or herbaceous aromatic notes typically detected in green fruit (McCarthy et al., 1963). When bananas ripened, esters become an important fraction of their aroma profile and the same aroma compounds were present in 1000 nl l^{-1} 1-MCP-treated and control fruit (Table 1). In addition to C_6 aldehydes, the amyl esters (2-pentylacetate or amylacetate; 3-methylbutylacetate or isoamylacetate; 3-methylbutylbutyrate or isoamylbutyrate; and the 3-methylbutyl, 3-methylbutyrate or isoamylisovalerate), responsible for the banana-like flavor, and the esters butylacetate, hexylacetate and butylbutyrate, with distinctive fruity notes, were present in both control and 1-MCP-treated bananas.

Quantitatively, no differences in the total amount of aroma compounds and in the level of the impact aroma compound isoamylacetate, between control and 1000 nl l^{-1} 1-MCP-treated fruit were detected during storage at 20 °C (Fig. 5A and D). Also, the total level of amyl esters was essentially the same in both control and 1-MCP-treated bananas (6013 and 6452 nl l^{-1}, respectively) after 8 days at 20 °C. However, a higher level of C_6 aldehydes was detected on day 8 and a lower concentration of esters on day 3 in the 1000 nl l^{-1} 1-MCP bananas (Fig. 5B and C), indicating

Table 1
Aroma compounds identified in control and 1-MCP-treated (1000 nl l^{-1} at 20 °C for 24 h) bananas

Aldehydes	Esters		
	Acetates	Butyrates	Others
Hexanal	2-Methylpropylacetate	Butylbutyrate	1-Methylbutyl, 2-methylpropanoate
(E) 2-hexenal	2-Pentylacetate	3-Methylbutylbutyrate	Methyloctanoate
(E) 2-nonenal	Butylacetate 3-Methylbutylacetate 2-Heptylacetate Hexylacetate	3-Methylbutyl, 3-methylbutyrate Octylbutyrate	

a slight delaying effect of 1-MCP on the production of volatiles.

3.2. Experiments 3, 4 and 5

In experiment 3, we selected bananas in a more advanced stage of ripeness (color 4) to apply 1000 nl l^{-1} 1-MCP for 6 h at 14 °C, the minimum safe temperature commercially used to extend the shelf life of bananas. In addition, we applied 1-MCP (same concentration and duration of exposure) at 20 °C on both color 3 and color 4 bananas. We found a significant increase in ethylene production and better retention of firmness in bananas exposed to 1-MCP at 14 °C, but no significant effects were found in respiration rate and skin color (Table 2). Bananas treated at 14 °C exhibited a lower ethylene production on day 6 and a better retention of firmness during storage at 20 °C, but no differences in respiration rate and visual color were detected. No differences in responses of stages 3 and 4 bananas to 1-MCP were found based on the evaluated parameters.

In experiment 4, stage 4 bananas were treated with 1000 nl l^{-1} 1-MCP at 14 °C for 12 or 24 h. Ethylene production, which was higher in 1-MCP-treated than in control fruit during 6 days at 20 °C was the only parameter that was influenced by 1-MCP applied for 12 or 24 h. Firmness was better retained in bananas treated with 1-MCP for 24 h only on day 6 (Table 3).

In experiment 5, we selected and characterized by color and firmness bananas at stages 2 ($h = 113$, 3.9 N), 3 ($h = 107$, 1.6 N) and 4 ($h = 100$, 1.3 N) to apply 1000 nl l^{-1} at 20 °C for 24 h. We found a significant increase in ethylene production by bananas at the three stages of ripeness. A clear delay in skin color yellowing was noted only stage 2 1-MCP-treated bananas, and a significant effect on respiration rate and firmness were observed with stage 4 bananas (Table 4).

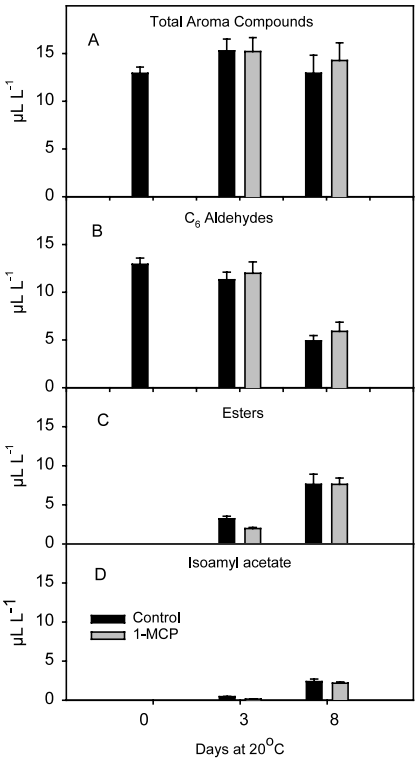

Fig. 5. Aroma compounds (means ± SD) of bananas treated with 1000 nl l^{-1} 1-MCP at 20 °C for 24 h and stored at 20 °C.

Table 2
Ethylene production, respiration and flesh firmness of bananas treated with 1000 nl l^{-1} 1-MCP for 6 h at 14 or 20 °C

Days at 20 °C after treatment	Stage of ripeness	Treatment	Application temperature (°C)	Ethylene production (µl kg^{-1} h^{-1})	CO_2 production (ml kg^{-1} h^{-1})	Flesh firmness[a] (N)
1	4	Control	14	0.35±0.02	60.1±4.5	1.71[b]±0.10
	4	1-MCP	14	0.43±0.04	60.5±2.1	–
	4	1-MCP	20	0.45±0.04	56.8±5.2	–
	3	1-MCP	20	0.48±0.70	63.4±13	
3	4	Control	14	0.54±0.06	46.6±4.2	1.39±0.08
	4	1-MCP	14	0.92±0.17	45.3±2.1	1.47±0.05
	4	1-MCP	20	1.10±0.16	43.1±4.9	1.29±0.05
	3	1-MCP	20	1.27±0.20	48.1±8.4	1.45±0.07
6	4	Control	14	0.84±0.10	44.8±2.4	1.09±0.03
	4	1-MCP	14	1.46±0.16	60.9±9.9	1.40±0.03
	4	1-MCP	20	1.71±0.17	65.1±8.3	1.29±0.03
	3	1-MCP	20	1.31±0.22	44.3±7.6	1.27±0.07
$LSD_{1\text{-}MCP}$ (5%)				0.03	6.2	0.08
$LSD_{temperature}$ (5%)				0.19	8.5	0.11
$LSD_{ripeness}$ (5%)				0.30	17.3	0.11

[a] Evaluated with a 3 mm probe.
[b] Initial value, before 1-MCP was applied. Visual color in all treatments was similar after 3 and 6 days at 20 °C.

Table 3
Ethylene production, respiration and flesh firmness of stage 4 bananas treated with 1000 nl l^{-1} 1-MCP for 12 or 24 h at 14 °C

Days at 20 °C after treatment	Treatment	Time of exposure (h)	Ethylene production (μl kg^{-1} h^{-1})	CO_2 production (ml kg^{-1} h^{-1})	Flesh firmness[a] (N)
1	$Control_{12}$[b]	–	0.40±0.29	46.5±3.2	1.69±0.1[c]
	1-MCP	12	0.58±0.07	49.9±2.3	–
	$Control_{24}$	–	0.40±0.08	45.5±0.5	–
	1-MCP	24	0.74±0.07	47.5±2.3	–
3	$Control_{12}$	–	0.51±0.07	35.7±1.7	1.27±0.05
	1-MCP	12	0.72±0.10	24.9±3.6	1.26±0.07
	$Control_{24}$	–	0.59±0.12	41.0±1.0	1.23±0.06
	1-MCP	24	0.85±0.04	37.7±4.0	1.25±0.02
6	$Control_{12}$	–	0.65±0.08	38.2±2.9	1.08±0.06
	1-MCP	12	1.45±0.13	41.3±3.4	1.22±0.12
	$Control_{24}$	–	0.75±0.06	42.1±1.3	0.97±0.06
	1-MCP	24	1.06±0.04	37.9±3.4	1.15±0.03
$LSD_{1\text{-MCP, 12 h}}$ (5%)			0.12	5.8	0.18
$LSD_{1\text{-MCP, 24 h}}$ (5%)			0.15	4.1	0.16

[a] Evaluated with a 3 mm probe.
[b] Control fruits were kept in closed glass jars for 12 or 24 h under the same conditions as 1-MCP-treated fruits.
[c] Initial value before 1-MCP was applied. Visual color in all treatments was similar after 3 and 6 days at 20 °C.

These results indicate lack of consistency in some 1-MCP effects. To illustrate these differences and variability, we summarized the relative responses of partially ripe bananas to 1-MCP in Table 5.

In experiment 1, we observed 1-MCP effects at 1000 nl l^{-1} on bananas at stage 3 in all evaluated parameters, but in experiment 5 only on ethylene production and skin color. In experiment 2, 1-MCP at 1000 nl l^{-1} at 20 °C for 6 h had a positive effect on skin color and firmness, but in experiment 3 no effect was observed on skin color with bananas in a similar stage of ripeness. When we applied the 1-MCP at 14 °C for 6 h in experiment 3, a positive effect on firmness was observed, but when the time of exposure was extended to 12 h in experiment 4, no effect on firmness was detected. Furthermore, no influence of stage of ripeness was observed in the efficacy of 1-MCP in experiment 3 on firmness, visual color and respiration rate (Table 2). However, in experiment 5, the strongest 1-MCP effect was observed on stage 4 bananas, which exhibited significant effects on ethylene production, respiration rate and firmness, while the effect of 1-MCP on stages 2 and 3 bananas was only significant on ethylene production and skin color.

Several factors can contribute to this variability and lack of consistency in results. It is difficult to define precise stages of ripeness in bananas just by external color. Not all ripening associated parameters in bananas were affected in the same magnitude by 1-MCP. The strongest 1-MCP effect was on ethylene production and the weakest effect was on respiration rate and in between were the softening process and the changes in skin color from green to yellow. Strong effects are difficult to mask by the inherent variability of samples, but weaker effects can be obscured by sample variability. Probably, depending on preharvest factors and postharvest handling and environmental conditions, bananas vary in their sensitivity to ethylene action and, consequently, to the inhibitory effect of 1-MCP. Variability in ripening rates among lots of fruit is commonly observed by commercial banana ripeners. Marin et al. (1996) found that hand position in the bunch and harvest season were not factors contributing to this

Table 4
Ethylene production, respiration, skin color and flesh firmness of stages 2, 3 and 4 bananas treated with 1000 nl l^{-1} 1-MCP for 24 h at 20 °C

Days at 20 °C after treatment	Treatment	Stage of ripeness	Ethylene production (μl kg^{-1} h^{-1})	CO_2 production (ml kg^{-1} h^{-1})	Skin color (visual color)	Flesh firmness[a] (N)
1	Control	2	0.86±0.21	29.5±3.8	3[b]	3.93±0.21[c]
	1-MCP	2	1.71±0.55	28.9±1.4	3[b]	–
	Control	3	0.63±0.55	36.0±0.5	4–5[b]	1.63±0.07[c]
	1-MCP	3	1.22±0.13	39.1±6.7	4[b]	–
	Control	4	0.56±0.03	55.5±4.5	5[b]	1.27±0.07[c]
	1-MCP	4	1.25±0.09	43.6±4.2	5[b]	–
3	Control	2	0.87±0.09	52.1±3.4	5	1.25±0.04
	1-MCP	2	1.89±0.39	47.0±5.6	4–5	1.34±0.08
	Control	3	0.89±0.21	44.1±3.1	6	1.08±0.10
	1-MCP	3	1.78±0.24	40.5±4.1	6	1.31±0.14
	Control	4	0.88±0.04	50.4 ± 1.4	6–7	0.96±0.11
	1-MCP	4	2.06 ± 0.25	42.2±2.4	6–7	1.38±0.04
6	Control	2	0.71±0.10	36.3±4.1	6–7	1.04±0.03
	1-MCP	2	1.16±0.21	35.2±2.7	5	1.09±0.06
	Control	3	0.91±0.13	36.7±1.7	7 overripe	0.94±0.06
	1-MCP	3	1.87±0.86	34.6±4.9	6–7	1.04±0.06
	Control	4	0.98±0.07	41.2±1.1	7 overripe	0.88±0.04
	1-MCP	4	2.38±0.56	37.8±1.1	7 overripe	1.14±0.04
$LSD_{MCPstage\ 2}$ (5%)			0.63	6.3	–	0.18
$LSD_{MCPstage\ 3}$ (5%)			0.45	7.6	–	0.32
$LSD_{MCPstage\ 4}$ (5%)			0.38	4.5	–	0.13

[a] Evaluated with a 3 mm probe.
[b] Values immediately after the application of 1-MCP.
[c] Initial value, before 1-MCP was applied.

Table 5
Relative responses of bananas to 1-MCP

Experiment	Stage of ripeness	Conditions for 1-MCP application			Range[a] of relative changes (%)			
		Concentration (nl l^{-1})	Temperature (°C)	Time of exposure (h)	Ethylene production	Respiration rate	*h*-Value or visual color	Firmness
1	3	100	20	24	NS	NS	NS	NS
	3	1000	20	24	+21–143	−15–55	+7–8	+53–130
2	3–4	1000	20	6	–	–	+1–10	+7–87
	3–4	1000	20	24	–	–	+4–12	+30–112
3	4	1000	14	6	+24–73	NS	NS	+28
4	4	1000	14	12	+41–122	NS	NS	NS
	4	1000	14	24	+43–86	NS	NS	+19
5	2	1000	20	24	+63–116	NS	+14–28	NS
	3	1000	20	24	+96–131	NS	+1–14	NS
	4	1000	20	24	+122–157	−16–21	NS	+30–44

[a] Minimum and maximum change in the MCP-treated relative to the control observed after 6 days at 20 °C.
NS = No significant differences.

variability and they conclude that factors such as country of origin and different transit conditions probably can explain this variability.

4. Conclusions

In the first part of this study, we found that exposure of bananas at ripeness stages 3 or 3–4 to 1000 nl l^{-1} 1-MCP for 6 or 24 h at 20 °C after approximately 36–48 h of having been commercially treated with ethylene, delayed changes in their skin color and flesh firmness without negative impacts on the qualitative or quantitative aroma composition of the fruit. However, these results could not be completely reproduced during the second part of the study. Thus, we conclude that, under the conditions tested in this study, the efficacy of 1-MCP in delaying further ripening of partially ripe (stages 3 and 4) bananas was too inconsistent to recommend commercial application. The potential use of 1-MCP as a supplement to modified atmospheres at 14 °C to delay ripening of partially ripe bananas merits further investigation.

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