ISSN: 1511-3701
Pertanika J. Trop. Agric. Sci. **32 (2)**: 125 - 132 (2009)

Responses of *Musa* AAA Berangan to 1-methylcyclopropene

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ABSTRACT

1-methylcyclopropene (1-MCP) is an inhibitor of ethylene perception and has been shown to delay the ripening of Cavendish bananas. Nevertheless, no work has reported the delay in the ripening of local bananas using 1-MCP. The objective of this study was to examine the responses of Berangan banana to 1-MCP applied at the ripening stage 1 (mature green) and ripening stage 2 (partially ripe). In Experiment I, 1 μL L^{-1} of 1-MCP was applied to mature green stage banana for 0, 2, 4 and 6 h, followed by ripening initiation using 10 g CaC_2 kg^{-1} fruit for 24 h. Meanwhile, in Experiment II, the fruits were partially ripened using 10 g CaC_2 kg^{-1} fruit for 24 h, followed by exposing them to 1 μL L^{-1} of 1-MCP for 0, 2, 4 and 6 h. Exposing mature green Berangan banana to 4 h of 1-MCP delayed degreening, retained flesh firmness and soluble solids concentration. On the contrary, exposing 1-MCP to the partially ripened banana fruit failed to delay both degreening and ripening processes. Fruit of both experiments ripened normally after the 1-MCP treatment, with more rapid ripening processes in partially ripe than mature green fruit.

Keywords: Peel colour, flesh firmness, soluble solids concentration, titratable acidity, pH

INTRODUCTION

Local bananas such as 'Berangan', 'Mas' and 'Rastali' are popular among Malaysians and ASEAN countries. The consumption and export for these bananas are expected to increase by 30% from 2005 to 2010 (Abbas, 2002). Bananas are climacteric fruit, once induced to ripen with ethylene or ethylene-generated resources, their marketing life is only about 3-5 d, depending on ethylene treatment and holding temperature after treatment. A method to slow down the ethylene-induced ripening process has economical significance for distribution centres, supermarkets and fruit stalls. Recently, 1-methylcyclopropene (1-MCP) has been reported to have inhibitory effects on ethylene action (Sisler *et al*., 1995). In particular, 1-MCP delays senescence of strawberries (Ku *et al*., 1999) and inhibits the degreening of oranges while not suppressing other ethylene-induced effects such as chilling injury (Porat *et al.,* 1999).

1-MCP has been shown to delay the ripening of 'Cavendish' banana (Golding *et al.,* 1998; Harris *et al*., 2000; Jiang *et al*., 1999a, b; Serek *et al*., 1995; Sisler *et al*., 1999; Sisler and Serek, 1999). Cavendish banana has been found to increase its 'green life' when treated with 1-MCP, where responses are being concentration-exposure time dependent (Jiang *et al*., 1999b; Harris *et al*., 2000; Bagnato *et al*., 2003). Jiang *et al*. (1999a) demonstrated that a 24 h exposure to either 500 or 1000 nL L^{-1} 1-MCP at 20˚C extended the green life

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of Cavendish bananas from 16 to 31 d in the absence of ethylene, as compared with the untreated controls. Jiang *et al*. (1999b) showed that a 1 h exposure to 1000 nL L^{-1} 1-MCP at 20˚C eliminated the ethylene effects for at least 5 d in Cavendish bananas, and that a 12 h exposure to 50 nL L^{-1} 1-MCP was just as effective. Joyce *et al.* (1999) found that banana ripening induced by propylene, an ethylene analogue, could 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. Jiang *et al*. (1999b) found that 1-MCP (in a concentration range 0.01-10 µL L^{-1} at 20˚C for 12 h), applied after 1 d of ethylene treatment, was found to slow the ripening of bananas down, but it was ineffective when applied 3 or 5 d after the ethylene treatment. To the best of authors' knowledge, no study has been carried out to delay the ripening of Berangan bananas using 1-MCP applied at mature green and partially ripe stage of ripening. Cultivar could affect the responses of product to 1-MCP (Abdi *et al*., 1998; Botondi *et al*., 2003; Watkins *et al*., 2000). Therefore, the objective of this study was to examine the responses of mature green and partially ripe Berangan bananas to 1-MCP.

MATERIALS AND METHODS

Plant Material

Hands of mature green bananas (*Musa* AAA Berangan) were obtained from Puchong Wholesale Market, Selangor, Malaysia. The fruits were sorted for freedom from the visual defects and uniformity of weight and shape. Two replicates of three hands, each containing 16-18 fingers per hand, were used in each experiment. Ansip-F® (0.009% a.i.) (Lytone Enterprise, Inc. Taiwan R.O.C.) was used to prepare 1-MCP. Seventeenth point six millilitre of distilled water at 40˚C was added into the beaker containing 1.1 g of crushed Ansip-F® tablets. The beaker was swirled for a few seconds before placing it into a 55 L container, and it was covered up immediately, sealed with Vaseline and tied up in a 0.035 mm thick PE bag to avoid gas leakage. After that, the container was left for 3 h before withdrawing the 1-MCP.

The application of 1-MCP was performed by placing the fruits in a 15 L box, with a 0.035 mm thick polyethylene (PE) bag and exposing them to 1-MCP gas for 0, 2, 4 and 6 h, respectively, at 27˚C with the relative humidity (RH) of 70%.

In Experiment I, 1 µL L^{-1} of 1-MCP was applied to ripening stage (RS) 1 (mature green) fruits. After the various exposure times, the fruits were ventilated and initiated to ripen using 10 g CaC_2 kg^{-1} fruits for 24 h. After 24 h, the fruit were again ventilated and allowed to ripen. In Experiment II, the fruits were initiated to ripen using 10 g CaC_2 kg^{-1} fruits for 24 h to partially ripe or RS 2. The peel of these RS 2 fruit was light green in colour. After exposing the fruits for 0, 2, 4 and 6 h 1-MCP, respectively, they were ventilated and allowed to ripen. Each 15 L box consisting of 24 fruits and analyses were carried out 2 d once until day 6.

Determination of Skin Colour

Skin colour was determined using Minolta CR-300 Chroma Meter (Minolta Corp., Osaka, Japan) using the Illuminate C (CIE, 1976) and results were expressed as lightness (L*), chroma (C*) and hue (h˚). The L* values ranged from 0 = black to 100 = white. The h˚ is an angle in a colour wheel of 360˚, with 0, 90, 180 and 270˚ representing red, yellow, green and blue, respectively, while C* is the intensity or the purity of the hue. The measurements at the stem end, mid region and floral end of each face of the peel were made and a mean value was obtained from two fruit per replicate.

Determination of Flesh Firmness

Flesh firmness was evaluated using the Bishop Penetrometer FT 327 (Alfonsine, Italy). The force required for an 11-mm probe to penetrate the cut surface in two opposite locations to a depth of 5 mm was recorded. The penetration force was expressed in kg cm^{-2} according to Ding *et al*. (2007).

Determination of Soluble Solids Concentration (SSC)

Ten g of fruit was macerated and the tissue was homogenised with 40 mL of distilled water, using a kitchen blender. The mixture was filtered with cotton wool. A drop of the filtrate was then placed on the prism glass of refractometer (Model N1, Atago Co., Ltd., Tokyo, Japan) to obtain the % SSC, according to Ding *et al*. (2007). The readings were corrected to a standard temperature of 20˚C by adding 0.28% to obtain % SSC at 27˚C.

Determination of Titratable Acidity (TA) and pH

The remaining juice from the SSC determination was used to measure TA by titrating with 0.1 mol L^{-1} NaOH, using 1% phenolphtalein as an indicator. The results were calculated as a percentage malic acid [(mL NaOH x 0.1 mol L^{-1}/ weight of the sample titrated) x 0.06705 x 100] according to Ding *et al*. (2007).

The pH of the juice was measured using a glass electrode pH meter, model Crison Micro pH 2000 (Crison Instruments, S.A., Barcelona, Spain). The pH meter was calibrated with buffer at pH 4.0 and 7.0, before being used.

Determination of Vitamin C Content

Ten g of banana flesh was well homogenised with 3% cold metaphosphoric acid, using a kitchen blender. The volume was made up to 100 mL and filtered with cotton wool. Then, 5 mL of the aliquot was titrated with 2,6-dichlorophenol-indophenol solution to a pink end-point. The vitamin C content was determined according to Ranganna's (1977) method, as follows:

$$\frac{\text{mg vitamin C}}{100\ \text{g}^{-1}} = \frac{\text{titre} \times \frac{\text{dye}}{\text{factor}} \times \frac{\text{volume}}{\text{made up}} \times 100}{\frac{\text{aliquot used}}{\text{for extraction}} \times \frac{\text{weight of}}{\text{sample taken}}}$$

Statistical Analysis

The experimental design was a completely randomised design with three replications of six fruit per replicate. Data were analysed using the analysis of variance (SAS Institute, Cary, NC) and the means were separated using the Duncan's multiple range test.

RESULTS

Experiment I

There was a significant difference ($P \leq 0.05$) in the L* values of Berangan bananas when exposed to 1-MCP (Table 1). The 1-MCP treated fruit, whether exposed for 2, 4 or 6 h, were found to have significant lower L* values as compared to the control. As ripening day progressed, fruit at day 0 had significant lower L* values, as compared to the other ripening days. By exposing Berangan bananas to 1-MCP for 4 and 6 h, the C* values were significantly lower than the control fruit (Table 1). Nevertheless, there was no significant difference in the C* values of Berangan banana as ripening day progressed (Table 1). The h^o values of Berangan bananas, treated with 4 h of 1-MCP, were significantly ($P \leq 0.05$) higher than 0 and 2 h 1-MCP treated fruit (Table 1). As ripening day progressed, the h^o values of the banana peel decreased significantly ($P \leq 0.05$) to about 101 at day 6 (Table 1). This value is equivalent to yellow in the colour chart, indicating that the fruit ripened as day progressed.

There was a significant difference ($P \leq 0.05$) in flesh firmness when Berangan bananas were treated with 1-MCP (Table 2). The firmness of the fruit flesh was retained by exposing it to 1-MCP for at least 4 h. However, the firmness of the flesh was found to significantly decrease ($P \leq 0.05$) by 34% as the ripening day progressed from 0 to 6 (Table 2). The SSC of Berangan was decreased significantly ($P \leq 0.05$) by exposing the fruit to 1-MCP for at least 4 h (Table 2), indicating that the ripening process was delayed. As ripening day progressed, the SSC of the fruit was increased by 302% (Table 2). The TA of Berangan banana fruit was not affected by 1-MCP treatment and ripening day (Table 2). Similar to the TA, the vitamin C content and pH of Berangan bananas were not affected by 1-MCP treatment and ripening day (Table 2).

TABLE 1
Peel colour (L*, C* and h°) of Berangan bananas, treated with 1 µL L^{-1} 1-MCP for 0, 2, 4 and 6 h, followed by the ripening initiation using CaC_2 for 24 h and the fruits are allowed to ripen for 6 d

Factor	L*	C*	h°
Exposure time, h (E)			
0	62.91 a[z]	38.73 a	100.47 c
2	57.84 b	34.13 ab	106.90 bc
4	56.26 b	29.18 b	115.46 a
6	54.29 b	31.43 b	113.20 ab
Ripening day (D)			
0	53.00 b	30.16 a	120.76 a
2	58.62 a	32.33 a	112.03 b
4	60.33 a	35.50 a	102.19 c
6	58.63 a	34.84 a	101.18 c
Interaction			
E x D	NS	NS	NS

[z] Mean separation within columns and factors by Duncan's at $P \leq 0.05$
[NS] Non significant at $P \leq 0.05$

TABLE 2
Flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), vitamin C and pH of Berangan bananas, treated with 1 µL L-1 1-MCP for 0, 2, 4 and 6 h, followed by the ripening initiation using CaC_2 for 24 h and the fruits are allowed to ripen for 6 d

Factor	Firmness (kg cm^{-2})	SSC (%SSC)	TA (%malic acid)	Vitamin C (mg 100 g^{-1})	pH
Exposure time, h (E)					
0	2.38 b[z]	13.50 a	2.05 a	10.08 a	4.94 a
2	3.50 ab	8.79 a	2.42 a	9.45 a	5.10 a
4	4.51 a	5.54 b	2.17 a	10.55 a	5.18 a
6	4.62 a	5.20 b	2.30 a	9.49 a	5.20 a
Ripening day (D)					
0	4.58 a	3.17 c	2.22 a	10.71 a	5.31 a
2	4.28 ab	7.13 bc	2.45 a	10.16 a	5.00 a
4	3.22 b	9.30 ab	1.81 a	9.52 a	4.94 a
6	3.04 b	12.74 a	2.54 a	9.00 a	5.22 a
Interaction					
E x D	NS	NS	NS	NS	NS

[z] Mean separation within columns and factors by Duncan's at $P \leq 0.05$
[NS] Non-significant or significant at $P \leq 0.05$

Experiment II

Exposing 1-MCP to RS 2 or partially ripe Berangan bananas did not have any effect on the L*, C* and h^o values of the fruit peels, as shown in Table 3. Apparently, once ripening has been initiated, 1-MCP could not inhibit ethylene development. As ripening day progressed, there was a significant difference ($P \leq 0.05$) in the L*, C* and h^o values of the peel colour. The L* values of the peels of Berangan increased significantly ($P \leq 0.05$) towards light colour as ripening day progressed (Table 3). The C* values of the fruit increased significantly from ripening day 0 to 4, and then decreased significantly to ripening day 6 (Table 3). The h˚ values of Berangan were significantly decreased by 31% to yellow-orange at ripening day 6 (Table 3).

The flesh firmness, SSC, TA, vitamin C and pH of Experiment II Berangan bananas did not show any significant differences among 1-MCP exposure times (Table 4). Once again, when the ripening was initiated, 1-MCP could not inhibit ethylene development. The flesh firmness of bananas was decreased significantly by 73% at d 6 of ripening (Table 4). The SSC of bananas was increased by 624% as ripening day progressed from 0 to 6 (Table 4). This is also similar to fruit in Experiment I, whereby TA and vitamin C of Berangan did not show any significant differences as the ripening day progressed (Table 4). The pH of the bananas in Experiment II decreased significantly as the fruit ripened from day 0 to 2, and no significant difference was observed thereafter.

DISCUSSION

The application of 1-MCP to mature green stage fruit has retained its peel colour and some quality characteristics of Berangan. Subjectively, the fruit treated with 1-MCP, either in Experiment I or II, showed a better visual appearance than the control fruit (data not presented). In specific, the L*, C* and h^o values of the fruit peels obtained in these two experiments reflected the yellow peel fruit for Experiment I, and yellow-orange

TABLE 3
Peel colour (L*, C* and h^o) of partially ripened Berangan bananas, using CaC_2 for 24 h, followed by the treatment of 1 µL L^{-1} of 1-MCP for 0, 2, 4 and 6 h, and the fruits are allowed to ripen for 6 d

Factor	L*	C*	h^o
Exposure time, h (E)			
0	63.78 a^z	40.17 a	98.50 a
2	61.10 a	38.19 a	99.68 a
4	61.86 a	38.25 a	99.26 a
6	61.85 a	38.14 a	98.75 a
Ripening day, (D)			
0	53.43 c	30.21 d	120.79 a
2	62.38 b	37.10 c	104.09 b
4	67.17 a	45.65 a	86.66 c
6	65.76 a	41.95 b	83.38 d
Interaction			
E x D	NS	NS	NS

^{z} Mean separation within columns and factors by Duncan's at $P \leq 0.05$
^{NS} Non-significant at $P \leq 0.05$

TABLE 4
Flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), SSC to TA ratio, vitamin C and pH of partially ripened Berangan bananas using CaC_2 for 24 h, followed by the treatment of 1 µL L^{-1} of for 0, 2, 4 and 6 h and the fruits are allowed to ripen for 6 d

Factor	Firmness (kg cm^{-2})	SSC (%SSC)	TA (%malic acid)	Vitamin C (mg 100 g^{-1})	pH
Exposure time, h (E)					
0	2.44 a[z]	13.41 a	2.34 a	8.01 a	4.81 a
2	3.01 a	13.63 a	2.28 a	7.72 a	4.80 a
4	3.11 a	14.25 a	2.49 a	7.70 a	4.83 a
6	3.21 a	14.17 a	2.51 a	7.68 a	4.75 a
Ripening day, (D)					
0	5.40 a	2.83 c	2.21 a	7.39 a	5.26 a
2	3.32 a	13.54 b	2.00 a	9.11 a	4.63 b
4	1.53 c	19.17 a	2.35 a	7.43 a	4.51 b
6	1.44 c	20.50 a	3.12 a	7.11 a	4.79 b
Interaction					
E x D	NS	NS	NS	NS	NS

[z] Mean separation within columns and factors by Duncan's at $P \leq 0.05$
[NS] Non-significant at $P \leq 0.05$

peel fruit for Experiment II by ripening day 6. The colour of the peel implied the ripeness of Berangan (Ding *et al*., 2006). The post-harvest life for the partial ripe fruit (Experiment II) was 6 d, while the fruit in Experiment I could last for 7 d (data not presented). This result is in agreement with the findings by Golding *et al*. (1998) and Jiang *et al*. (1999b) who found that the application of 1-MCP at mature green stage had delayed the colour changes in Cavendish peel. However, incomplete and uneven ripening of 1-MCP treated Cavendish banana fruit were reported by these authors. Nevertheless, this disorder did not happen to Berangan banana fruit in both experiments of this study. Harris *et al*. (2000) found that the uneven ripening of Cavendish banana was due to the variation in fruit maturity.

The result of this study also showed that by exposing Berangan bananas to 1 µL L^{-1} 1-MCP 4 h, at mature green stage, could sustain the flesh firmness and SSC of fruit (Tables 2 and 4). The flesh firmness and SSC of partially ripe fruit in Experiment II (Table 4) showed a tremendous change as compared to the ones in Experiment I (Table 2) when ripening progressed from day 0 to 6. In the study by Pelayo *et al*. (2003), the 1-MCP treatment was found to delay the colour changes in the peel and flesh firmness of partially ripe Cavendish banana. Jiang *et al*. (1999b) also reported that 1-MCP (in a concentration range 0.01-10 µL L^{-1} at 20˚C for 12 h), which was applied after 1 d of ethylene treatment, had slowed down the ripening of bananas. However, the subsequent experiments in Pelayo *et al*. (2003), the 1-MCP treatments were much less effective in retarding these partially ripe banana fruit. Therefore, it was concluded that the efficacy of 1-MCP, in delaying ripening of partially ripe Cavendish bananas, was too inconsistent for commercial application.

The finding of the present study indicated that once ripening of Berangan was initiated with the commencement of ethylene autocalatyitc,

the 1-MCP treatment could not inhibit ethylene development and its related ripening process. This study also showed that the peel colour changes, flesh firmness and SSC of Berangan banana were dependent on the functioning ethylene receptors during the first 24 h of CaC_2 treatment, as well as the number of active receptors rapidly increased after the initiation of ripening. Titratable acidity, vitamin C and the pH of Berangan banana in both experiments were not affected by the 1-MCP treatment. This showed that TA, vitamin C and pH of this banana type were not dependent on ethylene autocatalytic. Hence, the result gathered in the current study is inadequate to enable the researchers to draw a clear conclusion about the efficacy of 1-MCP in delaying the ripening of Berangan bananas. Further study, with broader resources and maturity of fruit, is therefore needed to draw a better conclusion.

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