Journal of Applied Horticulture, 10(2): 123-128, July-December, 2008

Effects of 1-methylcyclopropene on the postharvest life of Eksotika papaya

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Abstract

Papaya is a climacteric fruit, naturally fragile and cannot resist low temperature. Thus, prolonging the postharvest life of papaya fruit for long distance transportation is highly desirable to increase its commercialisation. 1-Methylcyclopropene (1-MCP) has been widely used to delay ripening and senescence of horticultural produces. The objective of this study was to determine characteristics of 'Eksotika' papaya treated with 1-MCP and optimum concentration of 1-MCP in prolonging postharvest life of papaya. Papayas were treated with 0, 10, 20, 30, 40 and 50 µL L^{-1} of 1-MCP for 7 days at 21˚C/90% relative humidity (RH). Then, the fruits were allowed to ripen at 26˚C/70% RH. 1-MCP did not affect L*, C*, soluble solids concentration, titratable acidity, pH, vitamin C and weight loss of papaya. The h° and firmness of papaya treated with 30 µL L^{-1} of 1-MCP showed significant high values as compared to other concentrations. Similarly, visual quality evaluation also showed that fruits treated with 30 µL L^{-1} of 1-MCP retained green colour for 9 days and by day 13, no disease infection and shriveling was found in these fruits as compared to other concentrations. There is potential to prolong postharvest life of Eksotika papaya using 1-MCP.

Key words: Papaya, *Carica papaya*, 1-MCP, colour, firmness, weight loss, visual quality

Introduction

Papaya (*Carica papaya* L.) is extensively grown in tropical regions of the world. Malaysia is the world's next largest exporter of papaya after Mexico with 25% of the world market share (Rabu and Mat Lin, 2005). Papaya is a climacteric fruit, naturally fragile due to its thin skin and cannot resist low temperature. Thus, it ripens and perishes rapidly. Normally fruits are harvested and placed to ripen at the recommended harvest stage (one yellow stripe) and it atains 60-70% yellow colouration within 4-6 days under ambient tropical conditions (25-28°C) (Rohani *et al.*, 1993).

For the maximum marketing period of papaya for export purpose, the fruit are transferred to low storage temperature (10-12°C) and can be stored for 14-21 days if harvested at one yellow stripe stage. Temperature below this range causes chilling injury and rapid deterioration in fruit quality. Postharvest life would be significantly reduced if fruits are harvested at advanced stages of ripening. Therefore, increasing postharvest life period of papaya has become a main issue for long distance transportation and commercialisation purposes. Moreover, when the postharvest life is prolonged, exporters who formerly use air freight can switch to sea transportation which is four times cheaper and also enable the fruit to be exported to distant countries like Saudi Arabia, United Arab Emirates, Australia and Japan (Rohani *et al.*, 1993).

One of the new technologies that can extend the postharvest life of papaya is use of 1-methylcyclopropene (1-MCP). 1-MCP is an inhibitor of ethylene perception that can markedly affect ripening or senescence processes of many horticulture products (Watkins, 2006). In general, 1-MCP delays ripening and senescence and reduces ethylene production, respiration, colour change and softening. This compound is used at low rates, has a non-toxic mode of action and is active at very low concentrations. The objective of this study was to determine characteristics of 'Eksotika' papaya after 1-MCP treatment and optimum concentration of 1-MCP in prolonging postharvest life of papaya.

Materials and methods

Plant materials: 'Eksotika' papayas at maturity stage 2 were obtained from Exotic Star (M) Sdn. Bhd., Kajang, Selangor, Malaysia. Fruits weighing 500-650 g, well-formed, uniform in size and colour, defect- and disease-free, were selected. Eight fruits were then packed into six cartons of 32 x 21 x 23 cm.

1-MCP application and storage: Papayas were treated with Ansip-F® (Lytone Enterprise, Inc. Taiwan R.O.C.) tablet, containing 0.009% 1-MCP active ingredient. 1-MCP concentrations used were 0, 10, 20, 30, 40 and 50 µL L^{-1}. The tablet form of Ansip-F was crushed and weighed for 0, 3.5, 7.0, 10.5, 14.0 and 17.5 mg according to the treatments of 0, 10, 20, 30, 40 and 50 µL L^{-1}, respectively. The crushed powder was held by cotton and later it was moisten with 5 mL 40°C distilled water and placed in the middle of carton with eight papaya fruits surrounding. The carton was then wrapped and tied up in a 0.035 mm thick polyethylene bag and stored for 7 days in a chamber at 21°C/90% relative humidity (RH). After 7 days, the cartons were ventilated and fruit were allowed to ripen in a room at 26°C/70% RH. Two fruits were analysed at interval of 2 days for skin colour, flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), pH, vitamin C content, weight loss and visual quality for 13 days.

Determination of skin colour: Skin colour was determined using a Minolta CR-300 Chroma Meter (Minolta Corp., Osaka, Japan) and results were expressed as lightness (L*), chroma (C*) and hue (h^o). The L* value ranges from 0 (black) to 100 (white). The h^o is an angle in a colour wheel of 360^o, with 0, 90, 180 and 270^o representing the red, yellow, green and blue hues, respectively, while C* is the intensity or purity of the hue. Measurements were carried out at stem end, mid region and floral end of papaya.

Determination of flesh firmness: Flesh firmness was evaluated using a computer controlled Instron 5543 Material Testing Machine (Instron® Ltd., High Wycomb, UK). Tissues were subjected to a puncture test at a constant speed of 20 mm min^{-1}, using a 5 mm diameter plunger probe. Three measurements were taken from stem end, mid region and floral end of a fruit for each day and penetration force was expressed in newtons.

Determination of SSC: Ten g of fruit was macerated and the tissue was homogenised with 40 ml of distilled water by 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. The readings were corrected for temperature compensation at 27^{o}C.

Determination of TA and pH: The remainder of the juice from the SSC determination was used to measure TA by titrating with 0.1 mol L^{-1} NaOH using 1% phenolphthalein as indicator. The results were calculated as a percentage citric acid [(ml NaOH x 0.1 mol L^{-1}/weight of sample titrated) x 0.064 x 100]. 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 papaya 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 colour. The vitamin C content was determined according to Ranganna (1977).

Determination of weight loss: Weight loss was determined by weight difference at days 7, 9, 11 and 13 compared with day 0, and expressed as percent (fresh weight basis). Fruits were weighed using a weighing scale.

Evaluation of visual quality: Visual quality of papaya fruits was evaluated based on the overall appearances of fruit such as skin colour, shriveling and disease from day 0 until 13.

Statistical analysis: The experimental design was a randomised complete block design with 4 replications. Data was analysed by using the analysis of variance (SAS Institute, Cary, NC) and means were separated by DMRT. Correlation analysis by using Pearson's correlation matrix was also performed.

Results and discussion

Skin colour: After a week of storage at 21^{o}C/RH 90%, 1-MCP treated fruit tended to be greener than control fruit when measured with a chroma meter and the values of L*, C* and h^o are presented in Table 1. Exposure to 1-MCP did not lead to significant differences in L* values of Eksotika papaya fruits (Table 1). However, L* values of Eksotika papaya fruits were significantly affected by days after exposure to 1-MCP. As days after 1-MCP treatment progressed, the L* values of Eksotika papaya fruits increased (Table 1) which means fruits had lighter skin as days progressed. This result is totally different from guava cv. 'Media China' that the L* values decreased after 7 days storage treated with 1-MCP at 25^{o}C (Mercado-Silva *et al.*, 1998) and 'Hass' avocados after 7 weeks storage with exposure to 100 nL L^{-1} 1-MCP for 6 h (Woolf *et al.*, 2005).

Table 1. 1-MCP concentration and day after 1-MCP treatment effects on skin colour (L*, C* and h^o) of 'Eksotika' papaya fruit. Fruits were treated with 1-MCP for 7 days at 21^{o}C/90%RH and thereafter allowed to ripen at 26^{o}C/70% RH until day 13

Factor	L*	C*	h^o
Concentration (C), µL L^{-1}			
0	55.66 a^z	36.84 a	115.37 f
10	53.98 a	34.24 a	126.78 c
20	55.44 a	36.56 a	136.41 b
30	55.65 a	35.72 a	141.23 a
40	55.40 a	36.15 a	118.83 e
50	54.73 a	34.99 a	121.47 d
Day 0 (before treatment)	48.81 e	25.58 e	166.06 a
Day after treatment (D)			
7	51.14 d	29.73 d	156.13 b
9	54.43 c	34.83 c	122.86 c
11	59.51 b	41.99 b	107.60 d
13	61.73 a	46.62 a	80.76 e
Interaction			
C x D	NS	*	**

NS, *, **Non significant (P>0.05) or significant (P≤0.05) or highly significant (P≤0.01), respectively.
[z]Mean separation within columns by DMRT at P=0.05.

The C* values refers to the vividness of colour and the C* values of Eksotika papaya fruits were not significantly affected by 1-MCP concentrations (Table 1). However, it is significantly affected by days after exposure to 1-MCP with significant increase as days progressed (Table 1). The h^o values of Eksotika papaya fruits were significantly affected by concentrations and days after exposure to 1-MCP (Table 1). The fruit treated with 30 µL L^{-1} of 1-MCP showed the most significant h^o values compared to other concentrations which reflect green in colour chart. Higher h^o values indicate that papaya fruits had a greater maintenance in green colour and application of 1-MCP delayed colour changes in the skin. The h^o values of fruits treated with 40 and 50 µL L^{-1} of 1-MCP was significantly lower than those treated with 30 µL L^{-1} of 1-MCP. This indicated that the fruits were more yellow than those treated with 30 µL L^{-1}.

The C* and h^o values of Eksotika papaya fruits skin were significantly affected by the interactions between concentration x day after 1-MCP treatment (Table 1). The h^o values of fruit skin decreased as days after 1-MCP treatment progressed indicating green skin turned to yellow (Fig. 1). After 9 days of 1-MCP treatment, skin of fruit treated with 30 µL L^{-1} of 1-MCP showed significant higher h^o values and this trend continued to day 11. The values of h^o and L* of Eksotika papaya fruit was negatively correlated (Table 2) indicating that the increase in the h^o values towards green colour was associated with a decrease in the L* values of Eksotika papaya fruit. Lower L* values indicated that Eksotika papaya fruits were darker in colour when the fruit skin was green.

Flesh firmness: There were significant differences in flesh firmness as affected by different concentrations of 1-MCP as

Table 2. Correlation coefficients (r) for) skin colour (L*, C* and h°), flesh firmness (Firm), soluble solids concentration (SSC), titratable acidity (TA), pH, vitamin C (VC) and weight loss (WL) of 'Eksotika' papaya fruit

	L*	C*	h°	Firm	SSC	TA	pH	VC
C*	0.90**	--						
h°	-0.73**	-0.76**	--					
Firm	-0.78**	-0.81**	0.89**	--				
SSC	0.18*	0.25**	-0.19*	-0.22*	--			
TA	0.02	-0.07	0.07	0.04	-0.10	--		
pH	-0.03	-0.06	-0.02	-0.08	-0.17*	0.03	--	
VC	0.39**	0.40**	-0.24*	-0.25**	0.15*	0.13*	0.12	--
WL	0.75**	0.76**	-0.83**	-0.87**	0.15*	-0.06	0.12	0.25*

For correlation coefficients, n = 240.
L* = lightness, C* = chroma and h°= hue angle.
*, ** significant and highly significant at $P \leq 0.05$.

well as days after 1-MCP treatment (Table 3). Similarly, there were highly significant interaction between 1-MCP concentration x day after 1-MCP treatment (Table 3). The flesh firmness of Eksotika papaya fruits treated with 30 µL L^{-1} of 1-MCP was significantly higher compared to other treatments while it was significantly lower in fruits treated with 40 µL L^{-1} of 1-MCP than other treatments. This result was different from 'Hass' avocados where fruit treated with 500 nL L^{-1} 1-MCP were firmer than fruit treated with 100 nL L^{-1} and all 1-MCP treated fruits were firmer than control fruit (Woolf *et al.*, 2005). For 'Pedro Sato' guava, the fruits that remained firm and did not reach full ripening were those treated with 900 nL L^{-1} compared to those treated with 100 and 300 nL L^{-1} (Bassetto *et al.*, 2005). This indicates that avocado and guava fruits treated with higher concentrations of 1-MCP were firmer than fruit treated with lower concentration of 1-MCP. However, in Eksotika papaya, the degree of firmness did not follow the same trend.

Fig. 2 shows the interaction effect on flesh firmness between day after 1-MCP treatment x 1-MCP concentration. The firmness of flesh treated with 30 µL L^{-1} 1-MCP was significantly higher compared to other treatments as days progressed from 7 to 11. Fruits treated with 20 µL L^{-1} showed significantly lower firmness than fruits treated with 30 µL L^{-1} but higher than other treatments as days after treatment progressed from 7 to 11. The firmness of papaya fruit was negatively correlated with L* and C* values but positively correlated with h° values (Table 2). This indicated that the firmness of fruit reduced as colour of fruit changed from green to yellow.

SSC: 1-MCP had no significant effect on the SSC of Eksotika papaya fruits (Table 3). However, there was a significant increase in SSC as days after 1-MCP treatment progressed from 11 to 13. There was no significant effect on SSC Eksotika papaya fruits between concentration x day after 1-MCP treatment (Table 3).

Similar findings were found in oranges (Porat *et al.*, 1999), apricots and plums (Dong *et al.*, 2002), custard apple and mango (Hofman *et al.*, 2001) and apples (Rupasinghe *et al.*, 2000; DeEll *et al.*, 2002) where SSC were unaffected by 1-MCP. The significant increase in SSC as days after 1-MCP treatment progressed from 11 to 13 indicated the fruit become much sweeter and more acceptable with increase in sugar content (Table 3). Chan (1979) confirmed that sucrose is the main sugar for papaya which consisted of 80% of total soluble sugars in fully ripened fruit. The SSC and flesh firmness of Eksotika papaya is negatively

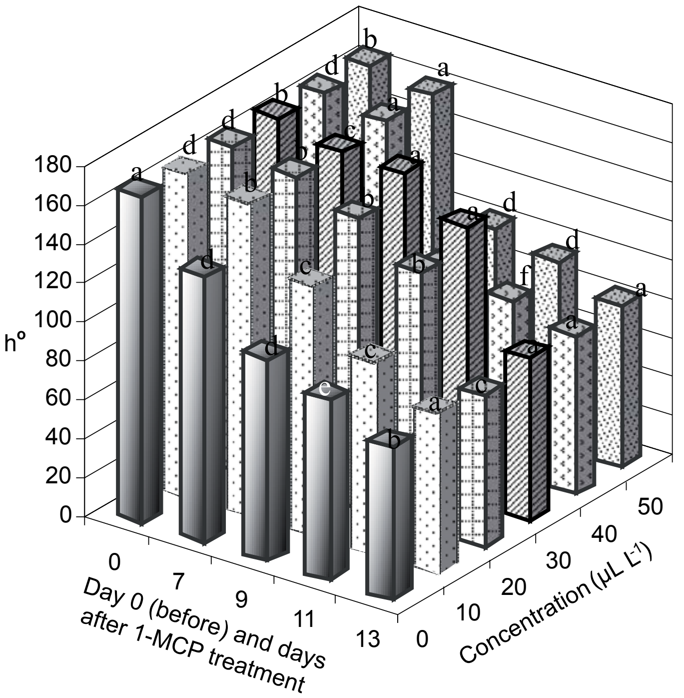

Fig. 1. Effects of day after 1-MCP treatment x concentration on skin colour (h°) of 'Eksotika' papaya fruit. Means separation pertaining to day after 1-MCP treatment by DMRT at P=0.05.

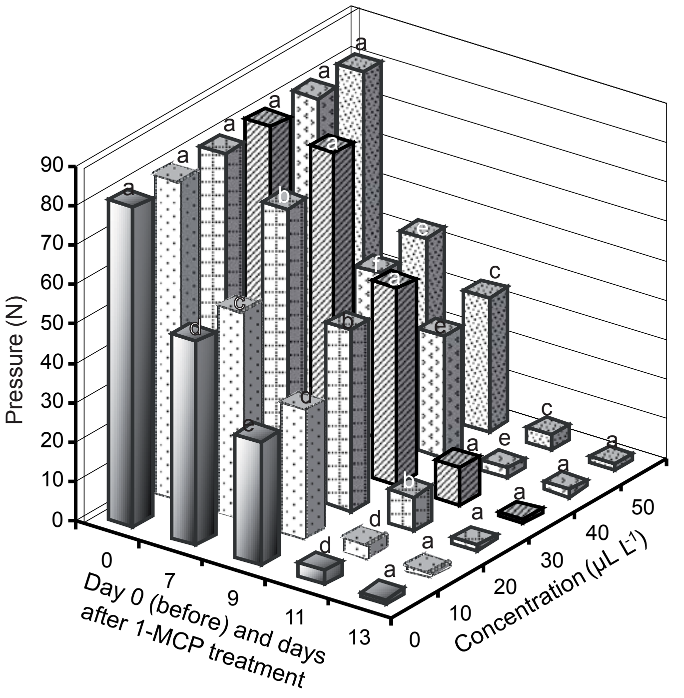

Fig. 2. Effects of day after 1-MCP treatment x concentration on flesh firmness of 'Eksotika' papaya fruit. Means separation pertaining to days after 1-MCP treatment by DMRT at P=0.05.

correlated (Table 2) because fruit became sweet and flesh softened when ripe.

TA: There was no significant difference in TA of Eksotika papaya when treated with six different concentrations of 1-MCP (Table 3). However, there was significant effect on TA of the Eksotika papaya fruits as days after 1-MCP treatment progressed. Initially the TA of fruit decreased, then increased and leveled off as days after treatment progressed (Table 3). Lazan *et al.* (1989) reported that the TA of Eksotika papaya fruit increased during ripening.

Table 3. Main and interaction effects between 1-MCP concentration and day after 1-MCP treatment on flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), pH, vitamin C and weight loss of 'Eksotika' papaya fruit. Fruits were treated with 1-MCP for 7 days at 21°C/90%RH and thereafter allowed to ripen at 26°C/70% RH until day 13

Factor	Firmness (N)	SSC (%)	TA (%)	pH	Vitamin C (mg 100 g^{-1})	Weight loss (%)
Concentration (C), µL L^{-1}						
0	33.74 d^z	6.24 a	0.40 a	5.39 b	24.91 a	4.14 a
10	34.27 c	5.79 a	0.39 a	5.62 a	23.30 a	4.06 a
20	41.88 b	6.34 a	0.37 a	5.60 a	26.23 a	4.19 a
30	44.24 a	4.78 a	0.31 a	5.68 a	23.33 a	4.43 a
40	31.77 f	4.76 a	0.31 a	5.68 a	24.82 a	4.15 a
50	33.08 e	4.85 a	0.34 a	5.68 a	23.74 a	4.03 a
Day 0 (before treatment)	81.23 a	4.33 b	0.34 ab	5.40 d	20.66 c	0.00 e
Day after treatment (D)						
7	56.99 b	5.42 b	0.45 a	5.78 a	24.02 bc	2.02 d
9	37.54 c	4.57 b	0.28 b	5.69 ab	22.29 bc	3.80 c
11	5.30 d	5.34 b	0.36 ab	5.61 bc	26.55 ab	5.98 b
13	1.41 e	7.64 a	0.33 b	5.55 c	28.42 a	8.65 a
Interaction						
C x D	**	NS	NS	*	NS	NS

NS, *, **Non significant (P>0.05) or significant (P≤0.05) or highly significant (P≤0.01), respectively.
^{z}Mean separation within columns by DMRT at P=0.05.

Citric acid is the major organic acid in Eksotika papaya and the level decreases slightly during ripening while malic acid levels remained unchanged whereas that of succinic acid increases steadily. Cis-aconitic, oxalic and fumaric acids are present in relatively low amounts in Eksotika papaya.

The effect of 1-MCP on TA is mixed, with some crops being affected and others not. 1-MCP did not affect TA in apricots (Dong *et al.*, 2002), 'Red Chief' apples (Mir *et al.*, 2001), 'Fortune', 'Angeleno' and 'President' plums (Menniti *et al.*, 2004) and 'Shamouti' oranges (Porat *et al.*, 1999). In contrast, higher TA values in 1-MCP treated fruit was found in 'Law Rome', 'Delicious', 'Empire' and 'McIntosh' apples (Watkins *et al.*, 2000), 'Elberta' peach (Fan *et al.*, 2002) and Pedro Sato (Bassetto *et al.*, 2005). Fan *et al.* (2000, 2002) also found lower acidity loss during storage in pears and plums treated with 1-MCP. In addition, 1-MCP alone did not affect fruit TA but in combination with wax, TA was higher on mamey sapote fruit (Ergun *et al.*, 2005).

pH: There was a significant increase in pH of Eksotika papaya fruits treated with 1-MCP as compared to control (Table 3). However, no significant difference was observed as the concentration of 1-MCP increased. As days after 1-MCP treatment progressed, pH of the fruit increased significantly from day 0 to 7, then decreased significantly (Table 3).

pH is a measure of solution acidity, in terms of hydrogen ions (H^+) and also buffering capacity of the extracted juice (Wills *et al.*, 1998). Most fruit pH increased throughout maturation was due to metabolic processes in the fruits that resulted in the decrease of organic acids (Coseteng and Lee, 1987). Organic acids are important source of respiratory energy in plant cell (Ulrich, 1970) and respiratory oxidation, tricarboxylic cycle, carboxylations and decarboxylations are the main pathway for metabolism of organic acids. In this study, there was no significant correlation between pH and TA (Table 2), indicating pH of Eksotika papaya was not correlated with its organic acids.

Vitamin C content: The concentrations of 1-MCP used did not affect the vitamin C content of Eksotika papaya (Table 3). However, there was a significant difference in vitamin C content of Eksotika papaya as days after 1-MCP treatment progressed with highest content on day 13. There was no significant interaction between 1-MCP concentration x day after 1-MCP treatment on the vitamin C content of Eksotika papaya fruit (Table 3).

In Pedro Sato guava fruit treated with 100, 300 or 900 nL L^{-1} 1-MCP at room temperature, vitamin C content was not influenced by 1-MCP (Bassetto *et al.*, 2005). The vitamin C content of Eksotika papaya fruits had a significant negative correlation with h° and flesh firmness (Table 2). As the h° values and flesh firmness decreases, vitamin C content increases. Thus the fruit had higher vitamin C content during ripening as the flesh of Eksotika papaya fruit softened and skin turned yellow. On the other hand, vitamin C content of Eksotika papaya fruits is positively correlated to the SSC (Table 2) indicating when fruit has high SSC, the vitamin C content is also high.

Weight loss: Weight loss was not significantly affected by different concentration of 1-MCP treatments (Table 3). However, there was a significant effect on weight loss of the Eksotika papaya fruits as day after 1-MCP treatment progressed. In contrast, there were no significant interaction between 1-MCP concentration x day after 1-MCP treatment (Table 3). No difference in weight loss was found in Eksotika papaya fruit between control and 1-MCP treated fruits at different concentrations of 1-MCP (Table 3). Manenoi *et al.* (2007) observed no difference in weight loss (7.4-8.8%) between the 1-MCP treated and non-treated papaya fruit.

Treatment of 1-MCP did not affect weight loss in oranges (Porat *et al.*, 1999), it delayed weight loss in avocado (Jeong *et al.*, 2002) and in 'Rendaiji' persimmon fruits treated with 1-MCP had less weight loss as compared to 1-MCP non-treated fruit (Ortiz *et al.*, 2005). Bassetto *et al.* (2005) reported that 1-MCP treated Pedro Sato guava fruit showed greater weight loss as compared to control fruit, probably due to the longer storage period. Total of 8.65% of weight loss occurred as fruits stored for 7 days at 21°C/90% RH (Table 3). The weight loss showed an increasing trend by 1.78, 2.18 and 2.67% as days after 1-MCP treatment progressed from 7 to 9, 9 to 11 and 11 to 13 day, respectively.

Weight loss of Eksotika papaya was negatively correlated with firmness and h° and positively correlated with L* and C* (Table 2). This indicated that weight loss occurred rapidly as fruit ripened and developed yellow and soft flesh.

Visual quality appearances: 1-MCP had a significant effect on papaya visual quality appearances depending on concentration being used and days after treatment as days progressed. The application of 1-MCP significantly delayed degreening as the fruits exhibited retention of green colour for 7 days at 21°C/90% RH especially those treated with 20 and 30 $\mu L\ L^{-1}$ of 1-MCP than control fruit which showed about 20% yellowness on the surface of fruit. On day 9, the skin colour of fruit changed obviously from green to yellow except fruits treated with 20, 30 and 50 $\mu L\ L^{-1}$ 1-MCP which showed little colour changes. On day 11, control and 10 $\mu L\ L^{-1}$ 1-MCP treated fruits showed 90% yellow, while 40 and 50 $\mu L\ L^{-1}$ fruit showed 70% yellow. Fruit treated with 20 and 30 $\mu L\ L^{-1}$ 1-MCP only showed 50% yellow. By day 13, disease infection and shriveling was found in control, 10, 40 and 50 $\mu L\ L^{-1}$ 1-MCP treated fruits. Fruit of 20 and 30 $\mu L\ L^{-1}$ 1-MCP treated show 100 and 90% yellow, respectively, without disease infection and shriveling.

According to Hofman (2001), 1-MCP treated papayas tended to have the same or slightly less severe disease rating at the end of shelf-life and disease was the primary reason for shelf-life termination of treated fruit. In this study, all fruits except 20 and 30 $\mu L\ L^{-1}$ 1-MCP treated fruits were infected by disease and shriveled at the end of postharvest life. Therefore, with higher concentration 1-MCP it is quite difficult to produce better quality of Eksotika papaya fruit. 1-MCP may inhibit a beneficial metabolic response or stimulate an undesirable characteristic, possibly relating to a natural defense mechanism (Ku *et al.*, 1999). Lower phenolic content in 1-MCP treated strawberries was considered to account for the increased disease incidence (Jiang *et al.*, 2001). Diaz *et al.* (2002) also found that treatment with 1-MCP increased susceptibility of tomatoes to *Botrytis cinerea*.

The results from this study demonstrated that the effectiveness of 1-MCP to extend postharvest life of papayas varied significantly according to the concentration of 1-MCP used. The use of 30 $\mu L\ L^{-1}$ 1-MCP was most effective in prolonging green life of Eksotika papaya fruit which remained green until day 9 after 1-MCP treatment. The current knowledge is still inadequate to enable us to draw a clear conclusion on whether 1-MCP is more effective in inhibiting the ripening of fruit when it is used with and without any combination with other postharvest treatments. This therefore leads to a greater potential for continued research on 1-MCP in extending the postharvest life of Eksotika papaya fruits.

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