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Evaluating the Effects of 1-Methylcyclopropene Concentration and Immersion Duration on Ripening and Quality of Banana Fruit

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Abstract

The influence of different concentrations of aqueous 1-methylcyclopropene (1-MCP) in delaying the ripening process of harvested banana fruit (*Musa* sp., AAA group, cv. BARI Kola-1) was investigated. Banana fruits at mature green stage were immersed in aqueous 1-MCP at 100, 300 and 500 µg L^{-1} for 5, 10 and 15 min, fan-forced air-dried and kept into 1% perforated low density polyethylene bag. The fruits were then stored at 20±2 °C and 75-80% RH for ripening over 35 days. Banana ripening was delayed when immersed in 100-500 µg L^{-1} 1-MCP solution however; higher concentrations were more effective. The efficacy of 1-MCP was not significantly influenced by immersion durations of 5, 10 and 15 min. The changes in respiration rate, fruit firmness, TSS, ascorbic acid contents and surface colour of bananas subjected to all three concentrations of 1-MCP remained strongly suppressed and consequently extended the storage life by 15 days compared to untreated fruit. Increased storage life of banana occurred without affecting the peel appearance, pulp texture, soluble solids concentration and aroma profiles. Nevertheless, crown rot disease initiated at the later stage of ripening although individual finger was not affected until end of the storage. Thus, postharvest immersion of banana fruit in aqueous 1-MCP at 100 µg L^{-1} solution for 5 min could extend the storage life up to 35 days without compromising fruit quality and could be a feasible alternative technology for long distance transportation and marketing.

Keywords

Banana
Ripening change
1-MCP
Respiration
Firmness
Storage life

INTRODUCTION

Banana is one of the most popular and widely grown fruit crop in Bangladesh. In banana, ripening is initiated either by the natural evolution of endogenous ethylene as the fruit reach full maturity or by using exogenous ethylene (Wills et al., 1998; Marriot, 1980). Once the fruit is ripened the storage life is limited due to its soft texture and susceptibility to diseases, which consequently restrict the handling and transportation of the fruit. A longer postharvest storage life is only possible by extending the pre-ripening period of harvested banana fruits. Extended postharvest life of banana is beneficial for transportation, storing and marketing for a longer period of time however; typically involves the use of sophisticated

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technologies and modern facilities. In such a need rapid cooling after harvest and storage at 13°C along with maintaining low ethylene levels can give a longer postharvest life of the fruit (McGlasson, 1985; Scott and Soertini, 1974; Wavhal and Athale, 1989). However, in developing countries, such as Bangladesh with limited facilities, alternative low-cost technologies are needed for extending the postharvest green life of banana at ambient temperature, which can be used by the producers and exporters for long-distance markets.

1-Methylcyclopropene (1-MCP), a novel gaseous anti-ethylene compound has proven of immense benefit for controlling the ripening and senescence of a number of fruits and vegetables (Blankenship and Dole, 2003; Watkins, 2006; Huber, 2008). Treatment with 1-MCP blocks ethylene action and delays ripening of climacteric fruit (Blankenship and Dole, 2003) and thereby extend the postharvest green life of tomato (Choi and Huber, 2008), banana (Jiang et al., 1999), guava (Mahajan and Singh, 2008) and minimally processed fruits and vegetables. Usually, 1-MCP is delivered in gaseous form in sealed environments for periods ranging from 1 to 24 hours at different concentrations. Recently, 1-MCP has been formulated for use as aqueous solutions, facilitating broader agricultural applications of the ethylene-action inhibitor (Elfving et al., 2007). Ripening of melting fleshy fruits like banana is associated with changes of colour and flavor factors such as soluble solids concentration, acidity and aroma (Watkins, 2008). Therefore, the use of 1-MCP can be more difficult for this type of fruit because it is necessary to delay, but not inhibit ripening. Thus, accurate concentration of 1-MCP and exposure time should perfectly be standardized for delaying fruit ripening. The objective of this research was to investigate the influence of aqueous 1-MCP concentration and immersion duration on the postharvest ripening, quality and storage life of green mature banana fruit.

Materials and Methods

Fruit materials

Locally grown banana fruits (*Musa* sp., AAA group, Gros Michel subgroup, var. BARI Kola-1) at mature green stage were acquired from a farmer's field of Gazipur, Bangladesh. At the time of harvest, the temperature and relative humidity of the banana field prevailed 28±2°C and 75±5%, respectively. After harvest, banana hands were transported to the Postharvest Laboratory, Horticulture Research Centre of BARI, Gazipur and cut into fingers using a sterilized sharp knife. Fruits were then sorted and grouped based on uniformity of developmental stage, weight and size, and then randomly divided into 12 treatment groups. Upon arrival no fungicide treatment was applied for controlling postharvest diseases.

1-MCP treatment

Twelve groups of 60 fruits each were treated with aqueous 1-MCP (0.1% active ingredient, AgroFresh, Inc., Rohm and Haas, Philadelphia). Solutions were prepared with granular 1-MCP at 100, 300 and 500 µg L^{-1} (*a.i.*). Quantities of 1-MCP granules containing the desired levels of active ingredient were suspended in 20 L of distilled water in 40 L plastic buckets and swirled gently with a plastic spatula until fully dissolved and then covered the bucket with its lid to protect the gas released from 1-MCP. Five minutes after preparation, banana fingers were immersed into each solution for 5, 10, and 15 min, and all treatments were completed within 30 min of 1-MCP solution preparation. A weighted and perforated plastic plate was placed on the fingers to ensure complete submerse during the emersion period. Banana fingers dipped in blank distilled water for 5, 10, and 15 min were used as control treatment. After removal from the bucket, fruit surface

water was quickly dried with a table fan. The fingers were then placed into 1% perforated low-density polyethylene bags (0.03 mm thick), each contained five fingers. The treated fingers were then stored for five weeks at 20±2°C and 75±5% RH for ripening. A set of 20 fingers from each treatment was used to determine the changes in respiration rate and surface colour. The same set of fruits was used throughout the whole storage period to get unique data. The remaining 40 fingers from each treatment were used to determine the flesh firmness and different chemical attributes at different storage interval. The experiment was laid out in Complete Randomized Design replicated thrice. Data on the changes in different physico-chemical parameters during storage were collected on day 0, 7, 14, 21, 28 and 35 of storage.

Determination of respiration rate

Respiration rate of banana was assayed at each measurement interval during storage. Ten fingers from each treatment were placed in 4 L airtight plastic containers equipped with septa and sealed for 2 h at 20±2°C. After incubation, 1 mL of gas sample was withdrawn from headspace by a gas-light hypodermic syringe and analyzed using a gas analyzer (CO_2/O_2 gas analyzer, Quantek Instrument, Model No. 902D, USA). The percentage of CO_2 evolved in the container gas was recorded. Then the respiration rate was calculated based on the total gas volume in the jar, fruit surface volume, fruit weight and incubation time and expressed as mL kg^{-1} h^{-1} of CO_2 evolved.

Assessment of pulp tissue firmness

Firmness analysis was performed using Fruit Texture Analyzer (GUSS, Model No. GS25, SA) supported by FTA Win Software. Firmness measurement was taken as the maximum penetration force reached during the tissue breakage and determined with 8 mm diameter stainless steel flathead probe, which penetrates in a normal direction at a cross-head speed of 5 mm S^{-1}. Round banana slices of 25 mm thick containing both peel and pulp were cut transversely from the stem end, equatorial and blossom end of each fruit with a sharp knife. After establishing zero-force contact between the probe and the horizontally positioned fruit, specimen was compressed 3 mm at 3 equidistant points of each slice and mean was calculated. The maximum force generated during probe travel was recorded and expressed in Newton (N).

Measurements of surface colour

Banana external colour was examined with a Chroma Meter (Model CR-400, Minolta Corp., Japan). CIE $L^*a^*b^*$ coordinates were recorded using D65 illuminants and a 10° standard observer as a reference system. L^* is lightness, a^* (-greenness to +redness) and b^* (- blueness to + yellowness) are the chromaticity coordinates. The a^* and b^* values were converted to chroma [$C = (a^{*2} + b^{*2})^{1/2}$] and hue angle [$h° = \tan^{-1}(b^*/a^*)$]. Before measurement, the equipment was calibrated against a standard white tile. Three readings were taken at different locations on each finger, taking five fingers from each treatment. Measurements were done in triplicate.

Measurements of ascorbic acid, total soluble solids (TSS), titratable acidity

For ascorbic acid measurement, 10 g of fruit tissue was homogenized in 50 mL of 3% cold metaphosphoric acid (HPO_3) using a blender for 2 min and filtered through Whatman filter paper No. 2. The clear supernatant was collected for assaying ascorbic acid by 2,6-dichlorophenol indophenol titration following the method of Ranganna (1986). Ten milliliters of aliquot was titrated with 0.1% 2,6-dichlorophenol indophenol solution until the filtrate changed to pink colour persisted for at least 15 seconds and the titration volume of 2,6-dichlorophenol indophenol

was recorded. Prior to titration 2,6-dichlorophenol indophenol solution was calibrated by ascorbic acid standard solution. Ascorbic acid content was calculated according to the titration volume of 2,6-dichlorophenol indophenol and results were expressed as mg 100 g^{-1} fresh weight.

Again, 10 g of fruit pulp was homogenized in 50 mL of distilled water for 2 min using a kitchen blender and filtered through Whatman filter paper No. 2. The supernatant was collected in order to determine total soluble solids by using hand-held Kruss refractometer (Model HR 900, SN 1200793, brix range 0-90% at 20°C, Germany), pH by glass electrode pH meter (Delta 320, Mettler, Shanghai) and titratable acidity, which expressed as citric acid (%) was determined by titration with 0.1 mol L^{-1} NaOH to pH 8.1 according to the method by Ranganna (1986).

Experimental design and statistical analysis

The experiment was carried out in a Completely Randomized Design (CRD) with three replications. The data were subjected to analysis of variance (ANOVA) using the CropState Statistical Software version 7.2. The results showing significant differences were then subjected to mean separation using Tukey's Studentized Range (HSD) Test at $P<0.05$. Analyzed data were graphically plotted using Microsoft XL software.

Results and Discussion
Changes in respiration rate

The rate of CO_2 production showed characteristic of climacteric respiratory pattern occurred during storage at 20±2°C (Fig. 1). Immediately after treatment, the CO_2 production of banana was about 14.3 mL kg^{-1} h^{-1} in control and 1-MCP treated fruits. The respiration rate in control fruit decreased until 7 d of storage from its initial value and then rapidly increased, reaching the maximum rate of 101 mL kg^{-1} h^{-1} on day 21 of storage. On the other hand, banana fruit treated with 1-MCP showed acute respiratory declines in response to 1-MCP treatment, particularly at 300 and 500 µg L^{-1}, about 68.5% over the first week of storage compared with 47.5% for the control fruit. Almost similar pattern in respiratory decline during initial storage period was also reported in other climacteric fruits, such as papaya (Rahman et al., 2012) and tomato (Choi and Huber, 2008). Choi and Huber (2008) reported that the respiratory rate of tomato fruit declined about 53% over the initial 3 d of storage at 20ºC when immersed in 200-600 µg L^{-1} 1-MCP solution for 1min, which was further supported by the results of the present study. In an earlier study, Golding et al. (1998) also observed the suppression of respiration in banana fruit when treated with propylene subsequently gassed with 1-MCP. All fruits treated with different concentrations of 1-MCP suppressed the respiratory production and delayed the onset of the respiratory climacteric, showing climacteric trends from about 14 through 35 d of storage. The delayed in respiratory climacteric was also reported in 1-MCP treated plums (Abdi et al., 1998; Dong et al., 2002). With storage beyond 14 d, respiration rates and patterns were significantly ($P<0.05$) similar in fruits treated with 1-MCP at 100, 300 and 500 µg L^{-1}, showing maximum CO_2 production rate of 99.5, 97.7 and 98.6 mL kg^{-1} h^{-1}, respectively at the end of 35 d of storage.

Changes in flesh firmness

At harvest, the initial firmness of mature green banana flesh was about 2.05 N, which generally decreased during storage at 20±2ºC (Fig. 2). However, the rate of decrease was significantly ($P<0.05$) reduced by 1-MCP treatment. Control fruits experienced a faster loss of firmness during storage, from initial values of 2.05 to 1 N

over the 21 d of storage period, leading to softening of fruits. In contrast, fruits treated with 1-MCP, particularly at 300 and 500 µg L^{-1} exhibited temporary slight increase in firmness during the early storage period of 7 d, reaching values 9.75 to 12.1% higher than initial values. Transient increases in firmness have also been reported for 'Florida 47' tomato fruit in response to treatment (Choi and Huber, 2008; Choi et al., 2009). Changes in firmness in fruit treated with 100 µg L^{-1} were nearly mid-way between control treatment and those treated at higher concentrations of 1-MCP throughout the whole storage period, reaching firmness value of 1.38 N on day 28 of storage. Firmness values for fruit treated at 300 and 500 µg L^{-1} following the initial increased declined slowly than other treatments, reached 1.47 and 1.56 N, respectively at 28 d of storage. However, flesh firmness was not detected in any fruit subjected to different treatments by the end of 35 d of storage due to complete ripening and softening of fruit flesh. Considering the firmness data, storage life of banana was extended by 15 d with the application of 1-MCP treatment compared to control. Findings of this study are in corroborate with Feng et al. (2000) who found that avocado ripening was delayed by about two weeks after 1-MCP treatment, then fruit ripened normally

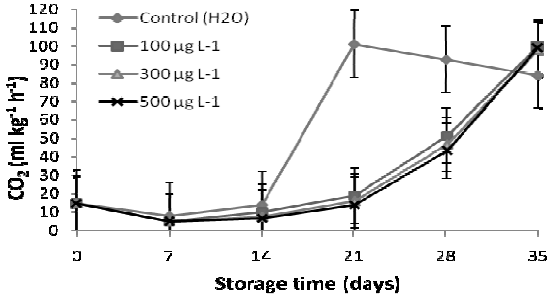


Fig. 1. Respiration of banana fruit during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at $P<0.05$. Vertical bars indicate standard error.

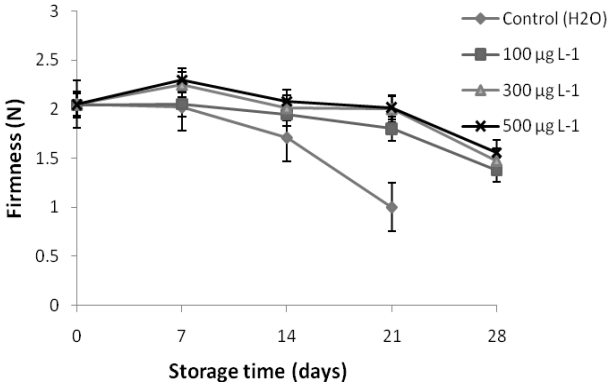
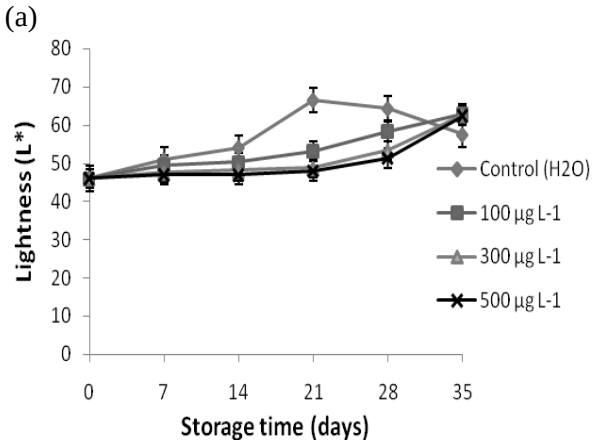
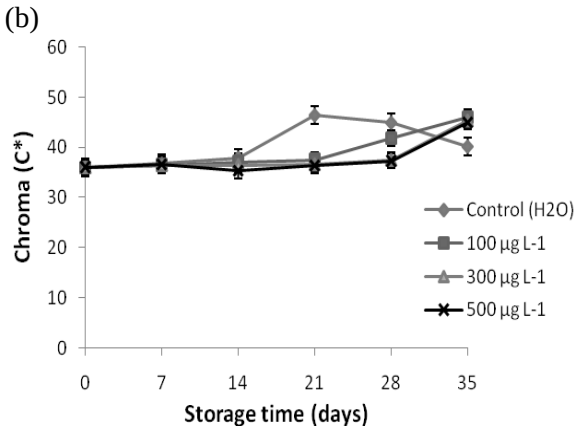


Fig. 2. Changes in flesh firmness of banana fruit during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at $P<0.05$. Vertical bars indicate standard error.





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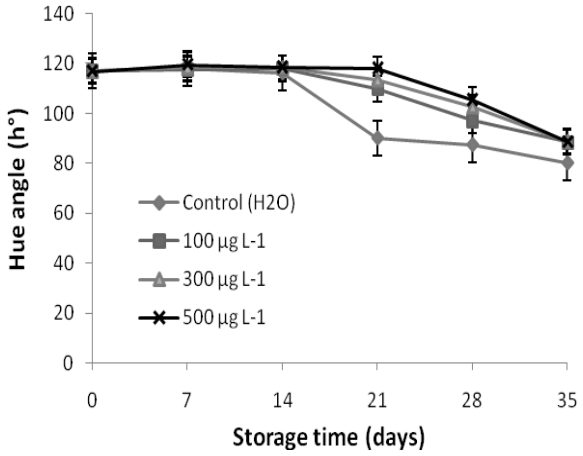

Fig. 3. Changes in lightness (a*), chroma (C*) and hue angle (h°) of banana peel during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at P<0.05. Vertical bars indicate standard error.

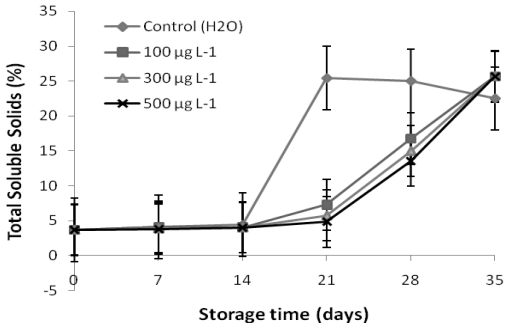

Fig. 4. Changes in total soluble solid contents in banana fruit during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at P<0.05. Vertical bars indicate standard error.

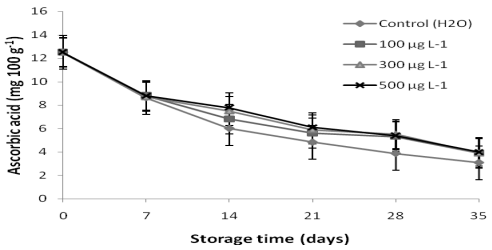

Fig. 5. Changes in ascorbic acid contents in banana fruit during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at P<0.05. Vertical bars indicate standard error.

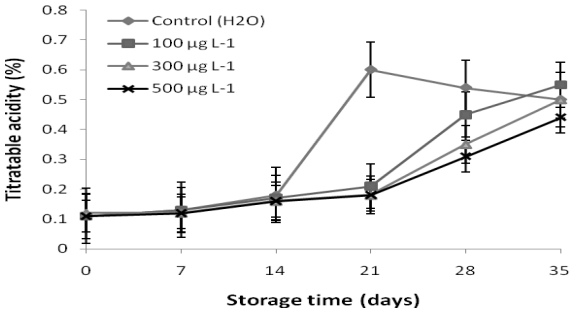

Fig. 6. Changes in titratable acidity in banana fruit during storage at 20±2°C following treatment with aqueous 1-methylcyclopropene at 100, 300 and 500 µg L^{-1}. Fruit immersed in water served as control. Means were separated by Tukey's Studentized Range Test (HSD) at P<0.05. Vertical bars indicate standard error.

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Bananas are highly susceptible for softening during ripening and it is essential to restrict softening through suitable postharvest techniques. Chen and Ramaswamy (2002) explained the kinetics of textural changes of banana during ripening. Tissue softening of fruit is mainly caused either by breakdown of insoluble protopectins into soluble pectins and starch degradation (Seymour et al., 1993; Mattoo et al., 1975). In this experiment, the maintenance of better firmness in 1-MCP treated banana fruit may be due its ability to delay production and action of ethylene during storage (Choi and Huber, 2008; Dong et al., 2002; Mathur and Srivastava, 2005). Similar findings in delaying tissue softening and ripening of fruits in response to 1-MCP treatment were reported for apricots (Fan et al., 2000), banana (Jiang et al., 1999), guava (Mahajan and Singh, 2008), nectarines (Dong et al., 2001), peaches (Kluge and Jacomino, 2002) and tomato (Choi et al., 2008; Choi and Huber, 2008).

Changes in fruit surface colour

The changes in peel colour of mature green banana fruit were significantly affected in

response to different concentration of 1-MCP treatments during storage. At harvest, the initial values of lightness (L*) and chroma (C*) were recorded as 46 and 36, respectively (Fig. 3a-3c). Generally, banana peel colour changed from green to yellow during storage, which corresponded to increase in L* and C* values of the colour scale. However, banana fruit immersed in 1-MCP solution exhibited a slower loss in green colour as indicated a more gradual increased in L* and C* values during storage, which was more acute in particular at higher concentrations. The L* values of bananas treated with 300 and 500 µg L^{-1} 1-MCP did not significantly (P<0.05) change from their initial values until 21 d of storage. After that period, the L* values of those treatments gradually increased following similar rate in change, reaching the maximum levels of 62.6 and 62.4, respectively at 35 d of storage. Almost similar pattern of increase in C* value was also observed in fruits treated with 300 and 500 µg L^{-1} 1-MCP during storage. Banana fruit immersed in 100 µg L^{-1} 1-MCP, on the other hand, exhibited a moderate rates of increase in L* and C* values between control and those treated at higher concentrations from about 7 d through 28 d, thereafter showing maximum levels of 62.9 and 46, respectively at the end of 35 d of storage. In contrast, the ripening associated colour change was more rapid in control fruit as evidenced by rapid increase in L* and C* values ranged from 50.9 to 66.5 and 36.8 to 46.5 after 7 to 21 d of storage, respectively. After 21 d of storage, both L* and C* values in control fruit were started to decline, exhibiting dull skin colour due to over ripening of fruit. Similar pattern of colour changes in banana fruits was also observed by Chen and Ramaswamy (2002) during storage.

The initial value of hue angle (h°) of mature green banana skin was 117 (Fig. 3c). Both in control treatment and 1-MCP treated bananas, the h° was almost constant until 14 d of storage, declined thereafter. 1-MCP treatments at all concentrations significantly reduced the rate of change as shown higher values of h° angle at each storage interval compared to control fruit. In control fruit, the h° was rapidly declined after 14 d of storage, reaching the value 90.2 on day 21 of storage, indicating complete yellowing of the fruit skin. In 1-MCP treated bananas, on the other hand, the change of skin colour from green to yellow was significantly delayed up to 21 d of storage, which corresponded to slight decrease in hue angle ranged from 118 to 113 after 7 to 21 d of storage, indicating green skin colour. The suppression of h° change however; was more pronounced in fruit treated with higher concentrations of 1-MCP (300 and 500 µg L^{-1}), exhibiting similar rate of decrease at each storage interval. This retention of green colour might be due to the delayed degradation of chlorophyll by 1-MCP treatment (Blankenship and Dole, 2003). After 21 d of storage, the h° values of all 1-MCP treated fruits rapidly declined, reaching about 88.7 at the end of 35 d of storage, showing yellow skin colour. At the end of 35 d of storage, a uniform ripening along with development of bright yellow skin colour was noticed in all bananas treated with different concentrations of 1-MCP. The development of yellow skin colour of 1-MCP treated bananas followed by softening was also reported by Sisler et al. (1996), which was further supported by the present findings.

During ripening of banana the total breakdown of chlorophyll occurs in yellow ripe fruits (Von Loesecke, 1929), while a slight reduction of carotenoid pigments like α-carotene and β-carotene occurs (Gross et al., 1976), which result a yellow colour fruit skin. The delay in the change of peel colour in response to 1-MCP treatment were reported in different fruits, such as banana (Jiang et al. 1999), tomato (Choi et al., 2008; Chio and Huber, 2008) and guava (Mahajan and Singh, 2008; Bassetto et al.,

2005), which was corroborated by the present findings.

Total soluble solids, ascorbic acid and titratable acidity

Changes of the total soluble solids (TSS) content in banana fruit with storage time is presented in Fig. 4. The initial TSS of all fruit samples was as low as 3.7%, which was nearly constant in both control and 1-MCP treated fruit until 14 d of storage, increased thereafter. In control fruit however; the TSS content was boosted up after 14 d of storage, reaching the maximum level of 25.4% at 21 d of storage. In contrast, TSS contents of banana fruits immersed in all 1-MCP concentrations tested, increased more gradually until 21 d of storage, rapidly increased thereafter, reaching maximum level of about 25.5% at the end of 35 d of storage. The accumulation of TSS in banana was simply delayed by 1-MCP treatment but total content in ripe fruit was similar to that in control treatment. Soluble solids were also unaffected by 1-MCP treatment in orange (Porat et al., 1999), apricots, plums (Dong et al., 2002), mango (Hofman et al., 2001) and apple (DeEll et al., 2002). All fruits treated with different concentrations of 1-MCP exhibited significantly (P<0.05) similar pattern and rate of increase in TSS throughout the whole storage period. 1-MCP reduced the rate of increase in TSS possibly due to suppress in respiration and ethylene production by the fruit with subsequent delay in ripening (Fan et al., 1999). Dadzie and Orchard (1997) stated that the TSS content of banana increases during ripening. In the flesh, more movement of water and the degradation of starch into soluble sugar might be contributed to the increase of TSS in fruits during storage (Wills et al., 1980).

It is evident that the 1-MCP treatment induced significant variation in the changes of ascorbic acid content in banana fruit during storage (Fig. 5). Immediately after treatment, the ascorbic acid content of mature green banana was recorded about 12.5 mg $100g^{-1}$, which gradually decreased over time, yielding significant (P<0.05) difference among the treatments on day 14 of storage and thereafter. With the control fruit, the quantity was rapidly decreased over time, reaching the value of 3.08 mg $100g^{-1}$ at 35 d of storage. Banana fruits subjected to 100, 300 and 500 µg L^{-1} 1-MCP treatments demonstrated more gradual decrease in ascorbic acid with similar (P<0.05) rate of change throughout the whole storage period and reached the values of 3.88, 3.95 and 4.0 mg $100g^{-1}$, respectively at the end of 35 d of storage. Loss of ascorbic acid content in control fruit was estimated as 75.3% by the end of stipulated storage period of 35 d, whereas it was about 68.5% in 1-MCP treated fruit. This result clearly indicated the potent effect of aqueous 1-MCP for slowing down the ripening process of banana fruit.

Generally, fruits and vegetables show a gradual decrease in ascorbic content as the temperature and storage duration increase (Lee and Kader, 2000; Adisa, 1986). Ripening process of fruit is associated with gradual or rapid depletion of ascorbic acid (Rouse and Aulin, 1977). In this experiment, 1-MCP treatment showed a significant (P<0.05) restriction in ascorbic acid losses in banana fruit compared to that in control. Such losses of ascorbic acid content was also reported in banana (Chauhan et al., 2006), tomato (Pantos and Markakis, 1973) and kiwifruit (Agar et al., 1999) during storage.

The change in titratable acidity (TA) of banana flesh as a function of different 1-MCP concentrations and storage time is shown in Fig. 6. The TA level in banana was slowly increased until 7 d of storage, yielding significant (P<0.05) differences among the treatments on and after 14 d of storage. Control fruit however; showed a rapid increase in TA level was with significantly (P<0.05) higher rate of change

compared to 1-MCP treated fruit, attaining the highest level of 0.6% after 21 d of storage, when the fruit was completely ripened. Then TA value started to decline until end of storage. Desai and Deshpande (1975) also reported that titratable acidity in bananas increased during ripening at 20°C and then decreased, which was corroborated with the present findings. Banana fruits treated with 1-MCP at 100, 300 and 500 µg L^{-1} suppressed the rate of increase in TA until 21 d of storage and rapid increase was occurred thereafter. Acidity levels at 35 d remained suppressed in response to increasing 1-MCP concentrations, reaching 0.55, 0.48 and 0.42% in the respective treatments. Findings of the present study are in agreement with Dadzie and Orchard (1997), who reported that the titratable acidity in banana flesh shows large increase and consequently pH decrease as ripening progress.

Influence of immersion duration on respiration, tissue firmness and skin hue of 1-MCP treated banana

The influence of different immersion durations (5, 10 and 15 min) on the efficacy of 1-MCP response was examined using three concentrations of 100, 300 and 500 µg L^{-1} 1-MCP. Results of the present study indicated that none of the physiological or biochemical changes of 1-MCP banana fruit such as respiration rate, flesh firmness, skin colour and nutritional values was significantly (P<0.05) influenced by immersion duration (Data are not presented because of insignificant effect of three immersion time). This was probably due to the longer immersion time even at the lowest level of 5 min, which might be sufficient for cuticular penetration of enough quantity of 1-MCP into banana skin. Findings of this study are in agreement with Bagnato et al. (2003), who reported that exposure periods from 24 to 72 h did not affect the efficacy of gaseous 1-MCP on extension of shelf life maintaining external and internal quality of 'Cavandish' banana. In contrast, different immersion duration, such as 0.5, 1, 3, 6 and 12 min had significant effect on the efficacy of aqueous 1-MCP on delaying the fruit softening and surface hue values of 'Florida 47' tomato (Choi and Huber, 2008). This might be due to the wider range of immersion duration, as brief as 30 s and increased up to 12 min. However, in that experiment, no significant (P≤0.05) difference was observed between 6 and 12 min exposure time, which was supported by the findings of the present study.

Ripening behavior and quality of 1-MCP treated banana

In terms of delaying banana fruit ripening, results of the present study confirm that 1-MCP is an effective anti-ethylene compound that has high potential for regulating the ripening of banana. Results of this experiment demonstrated that there was significant (P<0.05) difference regarding the responses of three concentrations (100, 300 and 500 µg L^{-1}) of 1-MCP used in this experiment, showing variations in suppressing the rate of changes of different parameters during storage, which clearly signified that the response of aqueous 1-MCP was concentration dependent (Watkins, 2008). Even so, the maximum storage life of 35 d was recorded for fruits immersed in all 1-MCP solutions at 100, 300 or 500 µg L^{-1} for 5 minutes. Similar degrees of storage life extension at those concentrations of 1-MCP may be explained by the saturation of the C_2H_4 binding sites (Macnish et al., 1997). The storage life, on the other hand, was recorded 20 d for control fruit, when all of them completely ripened with the development of bright yellow skin colour. Hence, ripening of green mature banana was delayed by at least 15 d compared to control treatment by postharvest dipping in 1-MCP solution, even at lowest concentration of 100 µg L^{-1}. All three concentrations of 1-MCP significantly (P<0.05) delayed but did not irreversibly suppress ripening of banana.

Rather, fruits kept in polyethylene bags following immersion in 1-MCP solutions ripened uniformly with bright yellow skin colour development, even with higher concentration of 500 µg L^{-1}. Jiang et al. (1999) also found almost similar results in normal ripening of bananas, which kept in polyethylene bags with gaseous 1-MCP at different concentrations ranged from 0.01 to 1.0 µl L^{-1}. Ripening uniformity may have been aided in this experiment by complete immersion of bananas into aqueous 1-MCP to allow all-over gas exchange, as bananas are known to have limited lateral gas exchange within their tissues (Perez and Beaudry, 1998). Findings of the present study are in agreement with Bagnato et al. (2003) who reported that 1-MCP treatment at lower concentration of 300 nL L^{-1} only delayed the ripening process of banana but firmness, skin colour, SSC and aroma profiles were similar with those of untreated fruit when compared at the same ripening stage. In contrast, however, Harris et al. (2000) concluded that 1-MCP had limited commercial potential because of the uneven colour development, and that this problem was exacerbated because of the range of maturities present in a commercial consignment. Nevertheless, crown rot disease caused mainly by *Colletotrichum musae* was initiated on the cut surface of the crown at the later stage of fruit ripening. However, individual finger was not affected by the disease until end of 35 d of storage. The ripened bananas were edible as compared with those ripening without 1-MCP treatment, and had the capacity to produce some acceptable aromatic flavours as judged by sensory evaluation, which were in corroborated with the findings of Jiang et al. (1999) and Golding et al. (1998).

Conclusion

The results of this study revealed that aqueous 1-MCP can be used as a simplistic and rapid means of delaying the ripening of harvested mature green banana fruit. Results of the present study demonstrated that, the effectiveness of 1-MCP to delay ripening process of bananas varied significantly according to the 1-MCP concentrations but not for dipping time. However, 1-MCP at lower concentration of 100 µg L^{-1} significantly delayed the ripening, which exhibited near about similar efficacy compared to those in higher concentrations. Ripening processes were attenuated normally when bananas were immersed in aqueous 1-MCP at 100 µg L^{-1} for 5 min, with all parameters eventually reaching values comparable to control fruit. The changes occurred during ripening, such as respiration rate, peel colour and fruit softening were markedly delayed, illustrating potential for commercial control of banana fruit ripening. Therefore, aqueous 1-MCP may have postharvest applications for regulating the ripening of banana wherein facilities favorable to application as a gas are not readily available.

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References

Abdi, N., McGlasson, W.B., Holford, P., Williams, M. and Mizrahi, Y. 1998. Responses of climactric and suppressed-climacteric plums to treatment with propylene and 1-methylcyclopropene. Postharvest Biology and Technology, 14(1): 29-39.

Adisa, V.A. 1986. The influence of molds and some storage factors on the ascorbic acid content of orange

and pineapple fruits. Food chemistry, 22(2): 139-146.

Agar, I.T., Massantini, R., Hess-Pierce, B. and Kader, A.A. 1999. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. Journal of Food Science, 64(3): 433-440.

Bagnato, N., Barrett, R., Sedgley, M. and Klieber, A. 2003. The effects on the quality of Cavendish bananas, which have been treated with ethylene, of exposure to 1-methylcyclopropene. International Journal of Food Science and Technology, 38(7): 745-750.

Bassetto, B, Jacomino, A.P., Pinheiro, A.L. and Kluge, R.A. 2005. Delay of ripening of "Pedro Sato" guava with 1-methylcyclopropene. Postharvest Biology and Technology, 35(3): 303-308.

Blankenship, S.M. and Dole, J.M. 2003. 1-Methylcyclopropene: a review. Postharvest Biology and Technology, 28(1): 1-25.

Chauhan, O.P., Raju, P.S., Dasgupta, D.K. and Bawa, A.S. 2006. Modified atmosphere packaging of banana (cv. Pachbale) with ethylene, carbondi-oxide and moisture scrubbers and effect on its ripening behavior. American Journal of Food Technology, 1(2): 179-189.

Chen, C.R. and Ramaswamy, H.S. 2002. Color and texture change kinetics in ripening bananas. Lebensmittel-Wissenschaft-und-Technologie, 35(5): 415-419.

Choi, S.T., Tsouvaltzis, P., Lim, C.I. and Huber, D.J. 2008. Suppression of ripening and induction of asynchronous ripening in tomato and avocado fruits subjected to complete or partial exposure to aqueous solutions of 1-methylcyclopropene. Postharvest Biology and Technology, 48(2): 206-214.

Choi, S.T. and Huber, D.J. 2008. Influence of aqueous 1-methylcyclopropene concentration, immersion duration, and solution longevity on the postahrvest ripening of breaker-turning tomato (*Solanun lycopersicum* L.) fruit. Postharvest Biology and Technology, 49(1): 147-154.

Choi, S T., Huber, D.J., Kim, J.G. and Hong, Y.P. 2009. Influence of chlorine and mode of application on efficacy of aqueous solutions of 1-methylcyclopropene in delaying tomato (*Solanun lycopersicum* L.) fruit ripening. Postharvest Biology and Technology, 53(1): 16-21.

Dadzie, B.K. and Orchard, J.E. 1997. Routine Post-Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods, INIBAP technical guidelines 2. CGIAR, Rome Italy; INIBAP, Montpellier, France; CTA, Wageningen, The Netherlands.

DeEll, J.R., Murr, D.P., Porteous, M.D. and Rupasinghe, H.P.V. 2002. Influence of temperature and duration of 1-methylcyclopropene (1-MCP) treatment on apple quality. Postharvest Biology and Technology, 24(3): 349-353.

Desai, B.B. and Deshpande, P.B. 1975. Chemical transformation in three varieties of banana (*Musa paradisica* Linn.) fruits stored at 20°C. Mysore Journal of Agricultural Science, 9: 634-643.

Dong, L., Lurie, S. and Zhou, H. 2002. Effect of 1-methylcyclopropene on ripening of 'Canino' apricots and 'Royal Zee' plums. Postharvest Biology and Technology, 24(2): 135-145.

Dong, L., Zhou, H., Sonego, L., Lers, A., Lurie, S. 2001. Ethylene involvement in the cold storage disorder of 'Flavortop' nectarine. Postharvest Biology and Technology, 23(2): 105-115.

Elfving, D.C., Drake, S.R., Reed, A.N. and Visser, D.B. 2007. Preharvest applications of sprayable 1-methylcyclopropene in the orchard for management of apple harvest and postharvest condition. HortScience 42(5): 1192-1199.

Fan, X., Argenta, L. and Mattheis, J.P. 2000. Inhibition of ethylene action by 1- methylcyclopropene prolongs storage life of apricots. Postharvest Biology and Technology, 20(2): 135-142.

Fan, X., Blankenship, S.M. and Mattheis, J.P. 1999. 1-MCP inhibits apple ripening. Journal of the American Society for Horticultural Science, 124(6): 690-695.

Feng, X., Apelbaum, A., Sisler, E.C. and Goren, R. 2000. Control of ethylene responses in avocado fruit with 1-methylcyclopropene. Postharvest Biology and Technology, 20(2): 143-150.

Golding, J.B., Sheater, D., Wyllie, S.G. and McGlasson, W.B. 1998. Application of 1-MCP and propylene to identify ethylene-dependent ripening process in mature banana fruit. Postharvest Biology and Technology, 14(1): 87-98.

Gross, J., Carmon, M., Lifhitz, A. and Costes, C. 1976. Carotenoides of banana pulp, peel and leaves. Journal of Food Science and Technology, 9(4): 211-214.

Harris, D.R., Seberry, J.A., Wills, R.B.H. and Spohr, L.J. 2000. Effect of fruit maturity on efficacy of 1-methylcyclopropene to delay the ripening of bananas. Postharvest Biology and Technology, 20(3): 303-308.

Huber, D.J. 2008. Suppression of ethylene responses through application of 1-methylcyclopropene: a powerful tool for elucidating ripening and senescence mechanisms in climacteric and non-climacteric fruits and vegetables. HortScience, 43(1): 106-111.

Jiang, Y., Joyce, D.C. and Macnish, A.J. 1999. Extension of the shelf life of banana fruit by 1-methylcyclopropene in combination with polyethylene bags. Postharvest Biology and Technology, 16(2): 187-193.

Kluge, R.A. and Jacomino, A.P. 2002. Shelf life of peaches treated with 1-methylcyclopropene. Scientia-Agricola, 59(1): 69-72.

Lee, S.K. and Kader, A.A. 2000. Preharvest and postharvest factors influencing vitamin C content of horticulture crops. Postharvest Biology and Technology 20(3): 207-220.

Macnish, A.J., Joyce, D.C. and Hofman, P.J. 1997. 1-methylcyclopropene delays ripening of 'Cavendish' banana fruit. In: Proceedings of Australasian Conference on Postharvest Horticulture, 28 September-3 October 1997, University of Western Sydney, Hawkesbury, NSW, Australia, pp. 282-284.

Mahajan, B.V.C. and Singh. G. 2008. Effect of 1-methylcyclopropene (1-MCP) on storage life and quality of winter guava. Journal of Food Science and Technology, 45(6): 537-539.

Marriott, J. 1980. Bananas-physiology and biochemistry of storage and ripening for optimum quality. Critical Reviews in Food Science and Nutrition, 13(1): 41-88.

Mathur, K. and Srivastava, G.C. 2005. Effect of 1-MCP on malic enzyme activity and ethylene production in mango during ripening. Indian Journal of Plant Physiology, 10(3): 273-275.

Mattoo, A.K., Murata, T., Pantastico, E.B., Chachin, K., Ogata, K. and Phan, C.T. 1975. Chemical changes during ripening and senescence. In: Post-harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables (Ed. Pantastico, E.B.). The AVI Pub. Co. Inc., Westport, Connecticut, pp. 103-127.

McGlasson, W.B. 1985. Ethylene and fruit ripening. HortScience, 20(1): 51-53.

Pantos, C.E. and Markakis, P. 1973. Ascorbic acid content of artificially ripened tomatoes. Journal of Food Science, 38(3): 550.

Porat, R., Weiss, B., Cohen, L., Daus, A., Goren, R. and Droby, S. 1999. Effect of ethylene and 1-methylcyclopropene on the postharvest qualities of 'Shamouti' oranges. Postharvest Biology and Technology, 15(2): 155-163.

Perez, R. and Beaudry, R.M. 1998. Fractional surface coating modifies gas diffusion and ripening in bananas. Journal of the American Society for Horticultural Science, 123(1): 115-118.

Rahman, M.A., Mahmud, T.M.M., Abdul Rahman, R., Kadir, J. and Begum, M.M. 2012. Potential co-application of *Burkholderia cepacia*, calcium and chitosan on enhancement of storage life and quality of papaya fruits. Pertanika Journal of Tropical Agricultural Science, 35(3): 439-458.

Ranganna, S. 1986. Handbook of Analysis and Quality Control for Fruit and Vegetable Products. 2nd ed. Tata McGraw-Hill, New Delhi, India.

Rouse, A.H. and Aulin, H. 1977. Ascorbic acid content in relation to ripeness in fruits of six *Hispophae rhamnoid* colonies. Annales Agriculturae Fenniae, 16(1): 80-88.

Scott, K.J. and Soertini, G. 1974. Effect of temperature on the storage life of banana held in polyethylene bags with ethylene absorbent. Tropical Agriculture, 51(1): 23-26.

Seymour, G.B., Taylor, J.E. and Tucker, G.A. 1993. Biochemistry of fruit ripening. Chapman & Hall, London.

Sisler, E.C., Serek, M. and Dupille, E. 1996. Comparison of cyclopropene, 1-methylcyclopropene and 3,3-dimethylcyclopropene as ethylene antagonists in plants. Plant Growth Regulation, 18(3): 169-174.

Von Loesecke, H.W. 1929. Quantitative changes in the chloroplast pigments in the peel of banana during ripening. Journal of the American Chemical Society, 51(8): 2439-2443.

Watkins, C.B. 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnology Advances, 24(4): 389-409.

Watkins, C.B. 2008. Overview of 1-methylcyclopropene trials and uses for edible horticultural crops. HortScience, 43(1): 86-94.

Wavhal, K.N. and Athale, P.W. 1989. Studies to prolonging shelf-life of mango fruits. Acta Horticulturae, 231(2): 771-775.

Wills, R., McGlasson, B., Graham, D. and Joyce, D. 1998. Postharvest: An Introduction to the Physiology & Handling of Fruit, Vegetables & Ornamentals. 4th ed. Wallingford: CAB International.

Wills, R.B.H., Bambridge, P.A. and Scott, K.J. 1980. Use of flesh firmness and other objective tests to determine consumer acceptability of delicious apples. Australian Journal of Experimental Agriculture and Animal Husbandry, 20(103): 252-256.