Application of 1-MCP to Intact Tomatoes Differing in Maturity Delays Quality Changes in the Stored Slices

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ABSTRACT

A study was carried out to determine the effect of 1-MCP applied to intact tomatoes differing in maturity stage on quality of stored tomato slices. 1-MCP (1 μL L^{-1}, 20 °C, 12 h) was applied directly to intact tomatoes from 'turning', 'pink', and 'light-red' stages of maturity. After slicing, slices were stored for up to 10 days at 5 ºC. 1-MCP maintained slice quality during storage following treatment of intact 'turning' and 'pink' maturity fruit as indicated by higher titratable acidity, higher ascorbic acid concentration, and lower lycopene content.1-MCP treatment did not significantly affect soluble solids and electrolyte leakage. Slices from 'light-red' maturity stage fruit did not respond to 1-MCP. The results show that application of 1-MCP to intact tomatoes was effective in maintaining tomato slice quality if 1-MCP is applied to fruit at early ('turning' and 'pink') stages of maturity.

Keywords: 1-methylcyclopropene, soluble solids, acidity, ascorbic acid, lycopene, electrolyte leakage

ABSTRAK

Aplikasi 1-MCP pada tomat berbagai kematangan menunda perubahan kualitas pada irisan tomat. Penelitian ini bertujuan untuk menentukan pengaruh aplikasi gas 1-MCP pada buah tomat dengan berbagai stadia kematangan terhadap perubahan kualitas irisan tomat. Gas 1-MCP (1 μL/L, 20 °C, 12 h) diaplikasikan pada buah tomat dengan stadia kematangan 'hijau-oranye', 'oranye' dan 'setengah-merah'. Sesudah pengirisan buah tomat, irisan tomat disimpan selama 10 hari pada suhu 5 ºC. Hasil penelitian menunjukkan bahwa aplikasi 1-MCP pada perlakuan buah tomat stadia 'hijau-oranye' dan 'oranye' menunda perubahan kualitas irisan tomat selama proses penyimpanan yang dicirikan dengan paramater keasaman yang dapat dititrasi yang lebih tinggi, konsentrasi asam askorbat yang lebih tinggi, dan kandungan likopen yang lebih rendah dibandingkan tanpa perlakuan 1-MCP. Perlakuan 1-MCP tidak nyata mempengaruhi parameter padatan terlarut dan kebocoran elektrolit. Irisan tomat dari buah tomat stadia 'setengah-merah' tidak memberikan respon terhadap aplikasi 1-MCP. Hasil penelitian ini menunjukkan bahwa aplikasi 1-MCP pada buah tomat efektif menjaga kualitas irisan tomat selama penyimpanan jika 1-MCP diaplikasikan pada buah tomat stadia awal kemasakan yaitu warna buah tomat 'hijau-oranye' dan 'oranye'.

Kata kunci: 1-methylcyclopropene, padatan terlarut, keasaman, asam askorbik, likopene, kebocoran elektrolit

INTRODUCTION

Tomato is a climacteric fruit and ripening is therefore regulated by ethylene (Saltveit, 1999). The application of an ethylene inhibitor, such as 1-methylcyclopropene (1-MCP), could further slow the ripening process and prolong storage (Efendi, 2005). In recent years the positive effects of 1-MCP in delaying deterioration and ripening of stored tomatoes has been demonstrated. Most of the research on the efficacy of 1-MCP to extend postharvest life has centered on 1-MCP application at the preclimacteric stage (Watkins and Miller, 2003), that is, before the induction of autocatalytic ethylene production. Although 1-MCP has the potential to delay the ripening of intact green tomatoes and to delay the senescence of ripe tomatoes, only a few studies have been conducted to determine if there are beneficial effects of 1-MCP on tomatoes that have already initiated ripening.

Selecting the optimum fruit maturity for fresh-cut production is a critical factor that affects eating quality and storage life (Watada and Qi, 1999). No study has reported on the effect of 1-MCP treatments on a range of tomato fruit maturities used for sliced tomatoes. Therefore it is important to determine whether 1-MCP would be more effective if applied on early maturity stage or at a later stage, since sensitivity of tissue to ethylene is affected by maturity.

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The objective of this study therefore was to evaluate the potential of 1-MCP to prolong storage life of fresh-cut tomato slices based on quality and nutritional changes.

MATERIALS AND METHODS

An experiment was conducted in the School of Agronomy and Horticulture, University of Queensland, Australia in 2005. Fruits of tomato cv. 'Revolution' were harvested at various maturities from commercial fields in Gatton, SE Queensland, Australia. After harvest, fruit were transported to the Postharvest Laboratory within 2 hours using an air-conditioned car. Fruit were sorted based on the stage of maturity and then on size. The three stages of maturity were characterized by color (hue angle, h°) and firmness (Newtons, N) as follows: 'turning' (h° 80-100; 21 ± 1.1 N), 'pink' (h° 63-77; 18 ± 1.0N), and 'light red' (h° 55-65; 15 ± 0.8 N). Medium-sized fruits were chosen with a mean fruit mass of 150.0 ± 14.6 g, and equatorial and longitudinal dimensions of 68.7 ± 1.6 mm and 65.4 ± 2.4 mm, respectively.

1-MCP Production and Application

Methods described by Macnish *et al.* (1999) were followed for 1-MCP treatments and quantification. The 1-MCP was generated from Ethylbloc® (0.14% active ingredient) when 0.5 g of Ethylbloc® was dissolved in 8 mL of water in a closed 775 mL bottle.

Stock 1-MCP was quantified by flame ionization gas chromatography at an oven temperature of 40 °C on a 1.22 m (length) by 3.2 mm (internal diameter) stainless steel column packed with 80 to 100 mesh Chromosorb P-AW. Injector and detector temperatures were 40 and 50 °C, respectively. The carrier gas was nitrogen at 2.4 kg cm^{-2}. N-butane (BOC Gases) was the standard gas used to quantify 1-MCP (Sisler and Serek, 1997).

There were 120 fruits consisting of 40 fruits from each maturity in this experiment. One set of 3 intact fruit each from 'turning', 'pink' and 'light-red' maturity stages were treated in 2.2 L glass jars with air containing 1 $\mu L\ L^{-1}$ 1-MCP for 12 hours at room temperature. All tomato fruit from the same maturity were treated in the same jar. A 50 mL beaker containing 1 M KOH was also placed inside the sealed jars to reduce CO_2 accumulation. Control fruits at the same maturity stages were maintained under identical conditions but without the 1-MCP. 1-MCP concentrations in the test jars were determined at the start and at the end of the 1-MCP treatment. During the 12 hour treatment, 1-MCP declined from 1.1 $\mu L\ L^{-1}$ to 0.9 $\mu L\ L^{-1}$. After treatment, lids were removed and 6 hours allowed for 1-MCP to dissipate before the fruit were sliced. Five slices of 7 mm-thickness were taken from 5 replicate fruit and vertically stacked in a separate ventilated plastic containers to ensure an aerobic atmosphere (Wu and Abbott, 2002), and stored at 5 °C.

Measurements

Slices were taken and analysed after 10 days for soluble solids, titratable acidity, electrolyte leakage, ascorbic acid concentrations and lycopene concentrations. Juice was extracted using a food blender for biochemical analyses. Soluble solids content was determined with a digital refractometer. Titratable acidity was determined by titrating 10 g of juice to pH 8.1 with 0.1 N NaOH. Electrolyte leakage was determined from conductivity measurements according to the procedure of King and Ludford (1983) and Hong *et al.* (2000). Ascorbic acid concentrations of pericarp discs were determined using High Performance Liquid Chromatography (HPLC) (LC-10 AD Liquid Chromatograph, Shimadzu, Japan) according to Rizzolo *et al.* (1984). Lycopene analyses were performed on pericarp discs according Hakim *et al.* (2000). Lycopene content was calculated using the formula developed by Fish *et al.* (2002) and using the molecular extinction coefficient of 17.2 x 10^4 (Mencarelli and Saltveit, 1988).

Experimental Design

Data were analysed as completely randomized designs. Each replication consisted of 5 slices from a single fruit, and each treatment was replicated 5-fold. The experiment was repeated twice. Mean separation was achieved using LSD at the 5% level of significance.

RESULTS AND DISCUSSION

Results

Soluble solids contents in slices from fruit at each stage of maturity were not affected by 1-MCP. However, soluble solids from 'light red' slices were significantly higher ($P < 0.05$) than 'turning' maturity slices (Table 1). Slices from 1-MCP-treated fruit from 'turning' and 'pink' maturities had slightly higher titratable acidities when compared with control fruit (Figure 1A). The effectiveness of 1-MCP in increasing acidity was much stronger in slices from 'turning' and 'pink' maturity than in slices from 'light red' maturity fruit.

Table 1. Effect of 1-MCP applied to intact tomatoes of differing in maturity on soluble solids (°Brix)

Treatments	Turning	Pink	Light Red
- 1-MCP	5.75	5.84	6.05
+1-MCP	5.80	5.89	6.12
Average	5.78b	5.86b	6.08a

Note: There were no effects of 1-MCP on soluble solids. Numbers followed by the same letter are not significantly different by LSD (5%)

Compared with the control slices (without 1-MCP), those from 'turning' and 'pink' fruit treated with 1-MCP had significantly lower ($P<0.05$) ratios of soluble solids/acidity during 10 days storage at 5 °C (Figure 1B). However, the ratio in slices from 'light-red' tomatoes was hardly affected by 1-MCP. 1-MCP had no influence on electrolyte leakage of slices from 'light red', 'pink' and 'turning' fruit. However, electrolyte leakage from 'light red' slices was significantly higher ($P < 0.05$) than from slices of 'turning' tomatoes (Table 2).

Table 2. Effect of 1-MCP applied to intact tomatoes of differing in maturity on electrolyte leakage (%)

Treatments	Turning	Pink	Light Red
- 1-MCP	0.38	0.41	0.46
+1-MCP	0.40	0.43	0.46
Average	0.39b	0.42b	0.46a

Note: There were no effects of 1-MCP on electrolyte leakage. Numbers followed by the same letter are not significantly different by LSD (5%)

Compared with the control slices (without 1-MCP), those slices from fruits at the 'turning' and 'pink' stages treated with 1-MCP had significantly higher ($P < 0.05$) ascorbic acid contents (Figure 2A) and lower lycopene contents (Figure 2B) than those in slices from 'light red' maturity fruit. Ascorbic acid contents of slices from 'turning' stage fruits were higher than those from 'pink' and 'light red' maturity slices. Ascorbic acid and lycopene contents of 'light red' stage slices were not affected by 1-MCP.

Discussion

1-MCP has been reported to have inhibitory effects on ethylene action in intact tomatoes (Moretti *et al.,* 2001; Wills and Ku, 2002), and extend postharvest life of fresh-cut products such as apple (Jiang and Joyce, 2002) and pineapple (Budu and Joyce, 2003). In this study, the main improvements in the quality of the sliced tomatoes treated with 1-MCP compared to the control were delayed loss of acidity (Figure 1A) and ascorbic acid (Figure 2A). In contrast, lycopene levels were lower (Figure 2B). For the present study, research was carried out at the early ripening

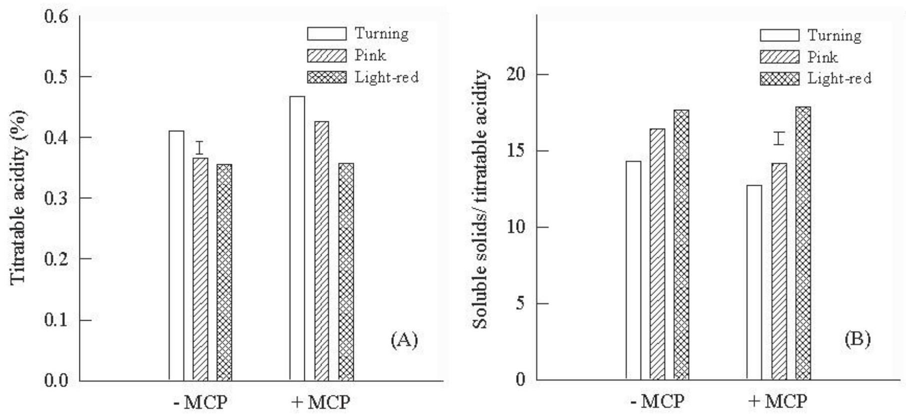

Figure 1. Effect of 1-MCP applied to intact tomatoes of differing maturity on titratable acidity content (% citric acid) (A), and on the ratio soluble solids/acidity (B), of tomato slices stored for 10 days at 5 °C. Vertical bars indicate LSD (5%); n = 5

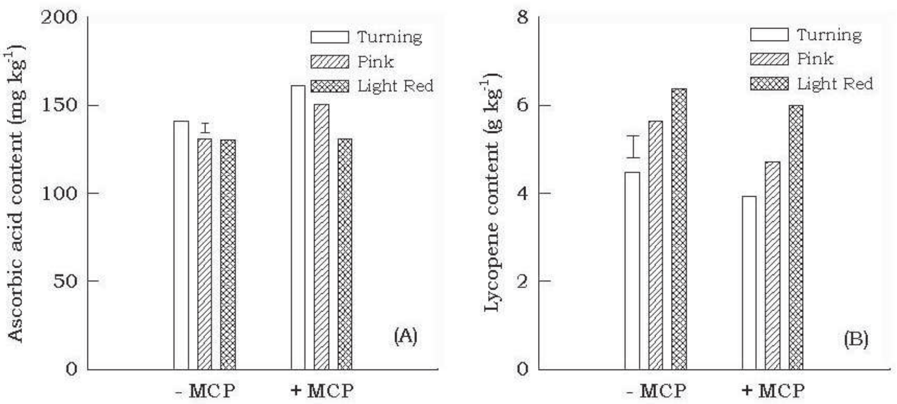

Figure 2. Effect of 1-MCP applied to intact tomatoes of differing maturity on ascorbic acid content (A), and on lycopene content (B), of tomato slices stored for 10 days at 5 °C. Vertical bars indicate LSD (5%); n = 5

stages ('turning' and 'pink' maturity) and rapidly ripening ('light-red') stages. It was found that the effectiveness of 1-MCP treatment in this experiment varied depending upon the stages of maturity. The more advanced the maturity, the lower the sensitivity to 1-MCP, as evaluated by the quality parameters tested.

1-MCP was applied to intact tomatoes at the climacteric stage ('turning' maturity) and early post-climacteric ('pink' maturity) stage and still significantly delayed ripening-associated events in the slices. In contrast, 1-MCP showed only a weak effect on all quality parameters in slices when applied to fruit from the 'light-red' stage. Other research results showed that the efficacy of 1-MCP is affected by fruit maturity. More mature fruit are usually less responsive to 1-MCP, such as in pear (Calvo, 2003) and banana (Jiang *et al.* 1999a; Jiang *et al.,* 1999b). Therefore, 1-MCP applied to 'turning' and 'pink' fruit may extend the storage life of sliced tomatoes during storage.

Higher levels of ascorbic acid were present with 1-MCP treatment of early ripening stage ('turning' and 'pink') fruits (Figure 2A). This result demonstrates that this 1-MCP postharvest technology is useful in keeping the nutritional quality of tomato slices. Working with intact tomatoes at 'turning' maturity, Xi-sheng *et al.* (2003) found the same results. Tay and Perera (2004) also showed that 1-MCP-treated lettuce were significantly higher in ascorbic acid than the untreated controls, and suggested that ascorbic acid is lost due to oxidation to dehydro-ascorbic acid (DHAA). They showed that levels of DHAA increased during 8 days of storage, and then levelled off. These results suggest that degradation of ascorbic acid in tomato fruit is slowed by 1-MCP. So far, the mechanisms that control ascorbic acid contents in many fruits are still unknown (Islas-Osuna *et al.* 2010). Therefore future studies on ascorbic acid biosynthesis could help us understand this mechanism.

Lycopene levels were depressed in slices from 1-MCP-treated fruit, especially when 1-MCP was applied to 'turning' and 'pink' maturity fruit. There was no effect on slices from the 'light-red' stage (Figure 2B). This pattern is consistent with results on juice color from Thompson *et al.* (2000), who suggested that hue angle of tomato puree is an indicator of lycopene content. Mostofi *et al.* (2003) found 1-MCP delayed the onset of lycopene increase by 18 days in 'mature-green' tomatoes stored at 15 °C. These results confirm that 1-MCP delayed ripening process as indicated by delayed lycopene synthesis and juice color development.

In this study there were no significant differences between the control and 1-MCP-treated tomatoes in soluble solids content (Table 1), confirming that sugar metabolism is ethylene independent (Goodenough, 1986). However, 1-MCP prevented the loss of acidity in slices from early maturity stages ('turning' and 'pink'), in line with Fernandez-Trujillo and Sanchez (2003) who also found retention of titratable acidity when tomatoes were treated with 1-MCP (1 $\mu L\ L^{-1}$, 20.5 h, 20 °C). This prevention of acidity loss by 1-MCP could be linked to the reduction in respiration rate and consequent reduced turnover of organic acids. Ripening was delayed when tomato fruit were treated with 1-MCP as indicated by lower ratio of soluble solids/titratable acidity in 'turning and 'pink' maturity slices (Figure 1B).

The delay in ripening in tomato slices following 1-MCP treatment was not accompanied by a reduction in the rate of membrane deterioration as measured by electrolyte leakage (Table 2) suggesting that senescence, as indicated by electrolyte leakage, was not affected by 1-MCP.

CONCLUSIONS

In conclusion, pre-treatment of tomatoes with 1-MCP at 'turning' and 'pink' maturity stages prior to slicing, has favorable effects on delaying postharvest ripening. Processes affected by 1-MCP include reduced loss in acidity and ascorbic acid concentration. Controlling slice ripening using the ethylene inhibitor 1-MCP could be commercially applied to tomatoes, particularly for fruit in the early stages of ripening ('turning' and 'pink'). When 1-MCP was applied at the 'light-red' maturity stage, effects were minimal.

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