THE EFFECT OF 1-MCP IN MAINTAINING THE QUALITY OF TOMATO SLICES

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ABSTRACT

Maintenance of quality traits is important during storage of fresh-cut produce. Changes in firmness, in tomato for instance, are ethylene-mediated. The objective of this study was to determine the suitability of the ethylene antagonist 1-MCP in maintaining the quality of tomato slices. Fruits of tomato cv. 'Revolution' were harvested at the 'pink' stage of maturity, treated with 1 μL.L^{-1} 1-MCP for 12 hours at 20 ºC, and sliced. Slices were stored as vertical stacks in closed plastic containers at 5 ºC for up to 10 days. Exposure of intact tomatoes to 1-MCP reduced ethylene production and respiration rate in slices, and produced firmer slices than when intact tomatoes were treated without 1-MCP. When intact tomatoes, at the 'pink' maturity stage were treated with several concentrations at 1-MCP (0.1, 1.0 or 10.0 μL.L^{-1}) at 20 ºC for 12 h, 1-MCP reduced both ethylene production and the respiration rate, delayed softening of the pericarp and inhibited loss in acidity when compared with slices from fruit not treated with 1-MCP. The most effective concentration of 1-MCP for inhibiting the ethylene-induced softening of tomato slices was 1 μL.L^{-1}.

***Key words**: ethylene, 1-MCP, tomato slices, quality*

INTRODUCTION

Stress caused by the slicing of tomato fruit during fresh cut processing may induce deteriorative processes. These processes include increased ethylene synthesis, elevated respiration rates, and faster softening (Artes et al., 1999; Mencarelli and Saltveit, 1988; Rolle and Chism, 1987; Watada et al., 1996). Rolle and Chism (1987) indicated that the majority of the colour, textural, and flavour changes that occur in fruits and vegetables during storage were affected either directly or indirectly by ethylene. This indicates that ethylene is a key factor that accelerates deterioration. The ability to minimise these deteriorative processes by inhibiting ethylene action could provide a powerful means to extend postharvest storage life of fresh-cut tomato slices.

The gaseous ethylene antagonist 1-methylcyclopropene (1-MCP) is an effective inhibitor of ethylene action at low concentrations. 1-MCP was thought to act by binding irreversibly to the ethylene receptors, so that ethylene cannot elicit signal transduction and translation (Sisler and Serek, 1997). Although 1-MCP is a potent inhibitor of ethylene action, it was not toxic to humans or animals (Serek and Sisler, 2001) and has been registered as a preservative for fresh fruit and vegetables in the United States (Kubo *et al*., 2003).[1]

The ripening process was regulated by an increase in ethylene production at the onset of ripening (Alexander and Grierson, 2002). Tomatoes require constant ethylene action for ripening to progress (Alexander and Grierson, 2002; Goodenough, 1986; Lelievre et al., 1997). Ethylene was found to be involved in the softening of stored tomato slices. Thus, application of the ethylene inhibitor 1-MCP, that reduces ethylene perception, might be a potential tool for controlling the ripening process and improving storage life and quality of tomato slices.

The compound 1-MCP has been used to retard ethylene-induced deterioration and senescence and to prolong the shelf life of fresh-cut apples (Jiang and Joyce, 2002; Perera *et al.*, 2003) fresh-cut pineapple (Budu and Joyce, 2003), broccoli florets (Ku and Wills, 1999) shredded lettuce (Wills *et al*., 2002). Fresh-cut apples treated with 1-MCP had reduced respiration and ethylene production rates and delayed softening and colour changes (Jiang and Joyce, 2002). Jiang and Joyce (2002) maintained that the degree of benefit generally increased with increasing 1-MCP concentration and duration of exposure. In cut pineapple pieces, Budu and Joyce (2003) showed that application of 1–MCP at higher concentrations (up to 5 μL.L^{-1}) reduced the respiration rate and maintained colour. Ku and Wills (1999) showed that 1-MCP (0.02 – 50 μL.L^{-1}, 1 – 6 h, 20 °C) markedly extended the storage life of broccoli florets through a delay in the onset of yellowing at 20 and 5 °C, and in delayed development of rotting at 5 °C. In shredded lettuce, Wills *et al.,* (2002) showed that application of 1-MCP (0.1 μL.L^{-1}, 1 h, 5 °C) resulted in an extension in storage life of about 50% over untreated lettuce.

The hypothesis being tested in this work is that ethylene-mediated deterioration of tomato slices can be prevented by the ethylene binding inhibitor 1-MCP. Suitability of 1-MCP was tested following the application of 1-MCP to intact tomatoes (before slicing) and to tomato slices, by evaluation of ethylene production, respiration rate, and quality traits.

MATERIAL AND METHODS

Plant Materials

The experiments were carried out in the Horticultural Postharvest Laboratory, "School of Agronomy and Horticultural", the University of Queensland, Australia in 2005. The tomato

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fruits were selected at the 'pink' stage of maturity with hue value 75 – 80°, firmness 20 ± 0.6 N, and medium size (weight 175 ± 15.6 g; equatorial diameter 73.26 ± 2.4 mm; length 68.8 ± 15.6 mm) and then washed with 100 ppm sodium hypochlorite before being minimally processed using a commercial tomato slicer.

1-MCP quantification and application

The methods described by Macnish *et al.* (1999) were followed for 1-MCP production and quantification. The 1-MCP was generated from EthylBloc® (Biotechnologies for Horticulture, Inc, USA, 0.14% active ingredient). The solution of 1-MCP was obtained by dissolving 0.5 g of EthylBloc® in 8 ml of water in a 775 ml bottle closed with a rubber injection port. When the 1-MCP gas was removed from the standard bottle with a syringe, saturated ammonium sulphate of the same volume was replaced to maintain a constant pressure.

The stock of 1-MCP was quantified using a gas chromatograph (GC-8AIT, Shimadzu, Japan) at an oven temperature of 40 °C using a 1.22 m (length) by 3.2 mm (internal diameter) stainless steel column packed with 80 to 100 mesh Chromosorb P-AW. The injector and detector temperatures were 40 °C and 50 °C, respectively. The 1-MCP was sensed with a flame ionisation detector. The carrier gas was nitrogen at 2.4 kg cm $^{-2}$. Isobutylene (100 μL.L^{-1}, BOC Gases) was used to quantify 1-MCP (Sisler and Serek, 1997).

1-MCP application

The 1-MCP was applied to intact tomatoes or slices in sealed 2.2 L glass jars. A 50 ml beaker of 1 M KOH was placed in the glass jars to reduce accumulation of CO_2. One set of intact fruit was treated with 1 μL.L^{-1} 1-MCP for 12 hours at 20 °C, and then left in air for 6 hours to allow 1-MCP to dissipate before the fruit were sliced. A second set of fruit was sliced, placed in the glass jars, and then treated with 1 μL.L^{-1} 1-MCP for 12 hours at 20 °C. The tomato slices without 1-MCP (control) were held in similar glass jars for the same time. During the 12 h treatments, 1-MCP concentration inside the jars was found to decline only slightly from 1.1 μL.L^{-1} to 0.9 μL.L^{-1}.

To determine the effect of concentration of 1-MCP applied prior to slicing, intact fruits were treated with 0.1, 1.0 and 10.0 μL.L^{-1} 1-MCP in air for 12 hours at 20 ºC in 2.2 L glass jars. After a further 6 h in air only, the intact fruits were sliced. Control fruits were treated with air only, in identical jars. During the 12 h treatments, the 1-MCP declined from 0.3 to 0.1 μL.L^{-1}, 1.0 to 0.9 μL.L^{-1}, and 10.1 to 9.9 μL.L^{-1}, respectively.

After treatment, 5 slices of 7 mm thickness were cut from each of 5 replicates of intact fruits and the slices were vertically stacked in ventilated plastic containers to ensure an aerobic atmosphere (Wu and Abbott, 2002), and then stored at 5 °C.

Assessments and experimental design

Slices were taken from storage and analysed for firmness, soluble solids, and titratable acidity. Headspace in jars was sampled and analysed for ethylene by a gas chromatography (Shimadzu model GC-8A fitted with a flame ionisation detector), and for CO_2 concentrations using a Shimadzu model GC-8A gas chromatograph fitted with a thermal conductivity detector. Pericarp firmness was determined at a speed 1 mm/sec by measuring the force required for a 4 mm diameter cylindrical probe to penetrate the cut surface 3 mm (Wu and Abbott, 2002). Juice was extracted using a food blender and was used for determining soluble solids content (with a digital refractometer Atago Digital Refractometer PR-101 (Fuji, Japan) and titratable acidity (by titrating 10 g of juice to pH 8.1 with 0.1 N NaOH). Data were analysed as a completely randomised design. There were five replicates per treatment, each consisting of five slices from a single fruit and 4 observation days in storage (days 1, 4, 7, 10). The experiments were repeated twice, and similar results were obtained. The difference was analysed usingLSD.

RESULTS

The effect of 1-MCP on rates of ethylene production and respiration

The effect of 1-MCP became obvious after 1 days, as compared with the non-treated slices (control). Slices from fruit treated with 1-MCP had signifantly lower (P,0.05) ethylene production (Figure 1A) and respiration rate (Figure1B). Differences remained until 4 days of storage. Ethylene production and respiration rate of slices following 1-MCP treatments did not differ (P>0.05) from those of the control from day 7 to day 10. The 1-MCP did not change the pattern f steady decline in ethylene production (Figure 1A) after 7 days, and respiration rates (Figure 1B) after 4 days, storage.

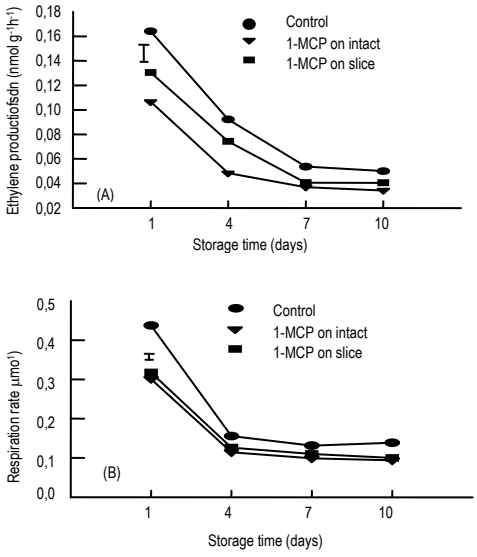

Figure 1. Changes in ethylene production (A) and respiration rate (B) of tomato slices as affected by 1-MCP (1 μL.L^{-1}, 12 h, 20 °C) during storage at 5 °C. Vertical bars indicate LSD $_{0.05}$.

The softening of tomato slices was markedly inhibited by 1-MCP application to intact tomatoes prior to slicing (Figure 2A). There was only small difference in firmness between untreated slices and 1-MCP-treated slices from day 1 until day 7 of storage. The compound of 1-MCP had no significant effect on hue angle of juice (Figure 2B), and data showed that hue angle gradually decreased during 10 days of storage, representing colour change from pink to light-red.

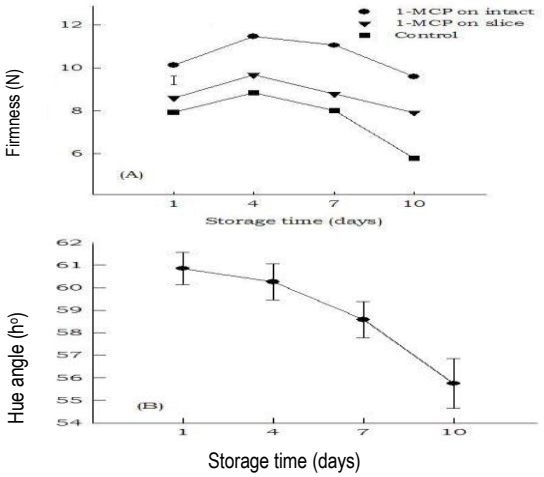

Figure 2. Changes in firmness (A) and hue angle (B) of tomato slices as affected by 1-MCP (1 μL.L^{-1}, 12 h, 20 °C) during storage at 5 °C. Vertical bars indicate LSD $_{0.05}$ (A) and SEM's in (B). As there were no effects of 1-MCP on hue angle, data are from all treatments combined.

The 1-MCP had no significant effect on soluble solids contents (Table 1) , however, soluble solids contents gradually increased during storage to day 7 (Figure 3A). The loss of titratable acidity from slices was markedly inhibited by 1-MCP (Figure 3B). Slices from 1-MCP treatments retained significantly higher (P<0.05) titratable acidity than the control slices throughout storage. However there was little difference in titratable acidity between slices from 1-MCP treatments.

Inhibition of ethylene production by slices was observed when 1-MCP was applied at 0.1, 1, and 10 μL.L^{-1} to whole tomatoes prior to slicing, from 1 day after slicing. The compound of 1-MCP at 1 μL.L^{-1} and 10 μL.L^{-1} inhibited ethylene production by the greatest amount (Figure 4A).

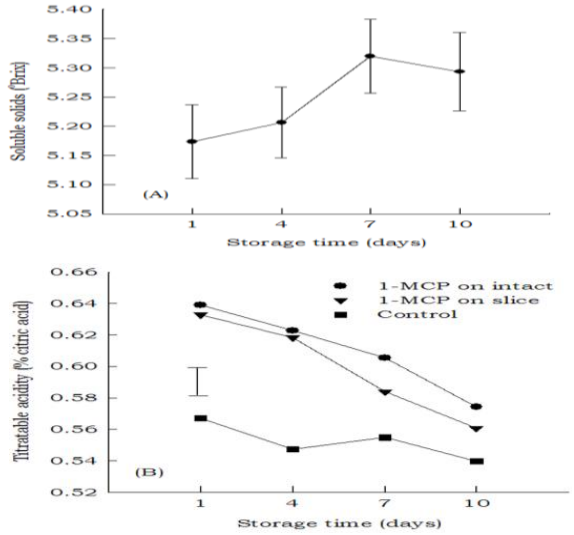

Figure 3. Changes in soluble solids (A) and titratable acidity (B) of tomato slices as affected by 1-MCP (1 μL.L^{-1}, 12 h, 20 °C) during storage at 5 °C. VerticaL.Lines in (A) represent SEM's, and as there were no effects of 1-MCP on soluble solids, data are from all treatments combined. In (B) the error bars represents LSD $_{0.05}$.

Table 1. The effect of 1-MCP and 4 storage days and th juice colour and solube solids.

Treatment	Juice colour (hue angle h^0)	Soluble solids (^{0}Brix)
Control	59.21	5.15
1-MCP on intact	59.84	5.23
1-MCP on slice	57.52	5.34
Treatment		
Day 1	60.85	5.17
Day 4	60.26	5.21
Day 7	58.57	5.32
Day 10	55.75	5.29

Note: There were no effects of 1-MCP on juice colour and soluble solids

Table 2. The effect of 1-MCP concentration and 4 storage days on the juice colour and solube solids.

Treatment	Juice colour (hue angle h^0)	Soluble solids (^{0}Brix)
Control 0.0 μL.L^{-1}	67.84	5.19
0.1 μL.L^{-1}	68.91	5.24
1.0 μL.L^{-1}	69.65	5.28
10.0 μL.L^{-1}	69.35	5.24
Treatment		
Day 1	70.42	5.14
Day 4	70.33	5.23
Day 7	69.06	5.29
Day 10	65.93	5.27

Note: There were no effects of 1-MCP on juice colour and soluble solids.

Inhibition of respiration rate was observed for 1-MCP-treated tomato slices at all concentrations (Figure 4B). As the concentration of 1-MCP applied to intact tomatoes was increased from 0.1, to 1 and to 10 μL.L^{-1}, the reduction in respiration rate was observable at day 1. In 4 days of storage, the different concentrations of 1-MCP did not significantly influence the respiration rate of the slices.

The softening of treated tomato slices was considerably reduced compared with the controls, especially following 4 days of storage at 5 °C (Figure 5A). There was indication that 10 μL.L^{-1} may have been supra-optimal, as firmness measurements data were lower than those recorded for 1 μL.L^{-1}. As with the previous experiment (Figure 2A), there were no significant differences in juice colour between slices when the fruit were treated with 1-MCP and the control (Figure 5B). Juice hue angle decreasing during storage, indicated changes in juice colour from pink to light- red.

As previously (Figure 3A), the 1-MCP had no significant effect on the soluble solids content (Table 2), but soluble solids increased after 7 days of storage at 5 °C (Figure 6A). The delayed loss of titratable acidity was observed from slices treated with 1-MCP, indicating treated slices retain titratable acidity during the treatment time and during storage. No differences (P> 0.05) in titratable acidity were found between 0.1 and 10 μL.L^{-1} treatments (Figure 6B), but the 1 μL.L^{-1} concentration retained the high acidity during storage.

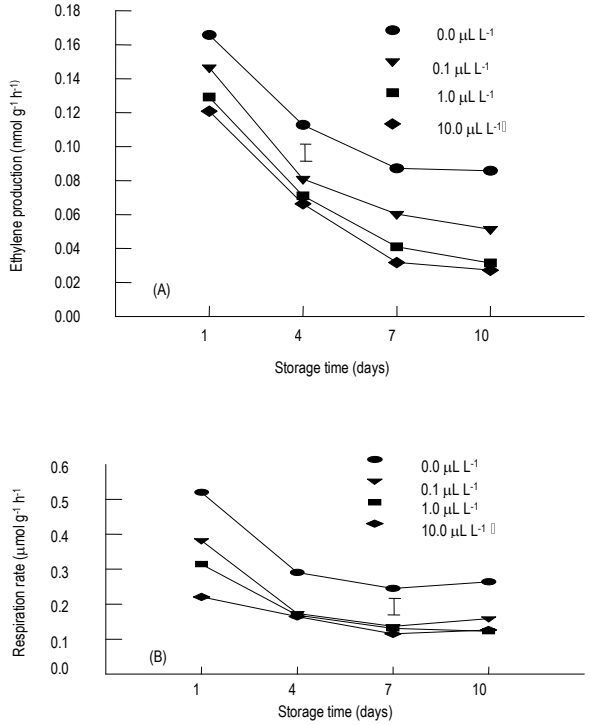

Figure 4. Changes in ethylene production (A) and respiration rate (B) of tomato slices as affected by different concentrations of 1-MCP (12 h, 20 °C, applied to intact fruit) during storage of slices at 5 °C. Vertical bars indicate LSD $_{0.05}$.

Effect of 1-MCP concentration on quality

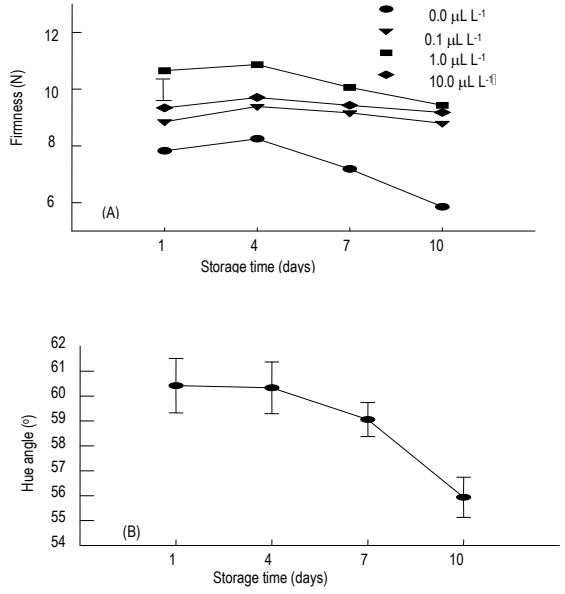

Figure 5. Changes in firmness (A) and juice hue angle (B) of tomato slices as affected by different concentrations of 1-MCP (12 h, 20 °C, applied to intact fruit) during storage at 5 °C. Vertical bars in (A) indicate LSD $_{0.05}$ and in (B) indicate SEM's.

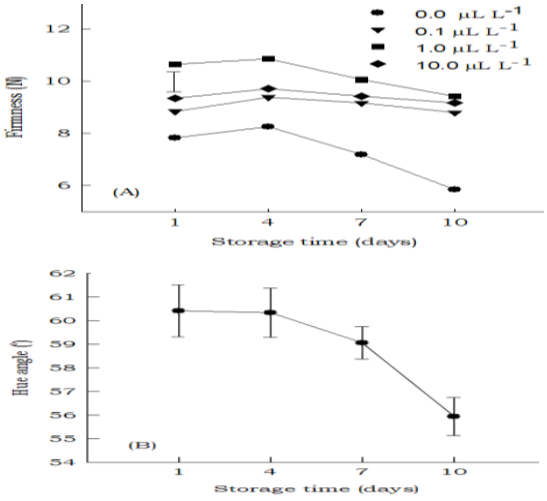

Figure 6. Changes in soluble solids (A) and titratable acidity (B) of tomato slices as affected by different concentrations of 1-MCP (12 h, 20 °C) during storage at 5 °C. Vertical bars in (A) indicate SEM's. In (B), the error bar indicates LSD $_{0.05}$.

DISCUSSION

Ripening of tomatoes is controlled by the plant hormone ethylene. As tomatoes starting to ripe, ethylene stimulated its own synthesis (i.e. autocatalytic ethylene production) (Alexander and Grierson, 2002; Saltveit, 1999) and resulted in physiological changes such as tissue softening and changed in sugars and organic acids (Giovannoni, 2001). These effects lead to an acceleration of the ripening process, as indicated by loss in firmness, and finally to a short storage life. The ethylene perception inhibitor 1-MCP was a tool to study the role of ethylene in senescence process and was also able to extend the shelf life and quality of plant products (Blankenship and Dole, 2003).

In this experiment on tomato slices, application of 1-MCP to tomato fruit prior to slicing was effective in reducing ethylene production (Figure 1A and 4A), and respiration rate (Figure 1B and 4B), in maintaining slice firmness (Figure 2A and 5A), and in reducing the loss of titratable acidity (Figure 3B and 6B). From results of this experiment, it could be deduced that the lack of ethylene perception was one of the mechanisms whereby 1-MCP inhibited ripening as expressed through changes in firmness, soluble solids and titratable acidity. Therefore, it is possible that blocking wound ethylene induced by the cutting procedure may directly extend shelf life by reducing the loss of tissue firmness of tomato slices. Application of 1-MCP to intact tomatoes before slicing was effective in reducing ethylene production, possibly because it inhibits autocatalytic ethylene production. It is thought that 1-MCP binds to the cellular ethylene receptors, and that it blocks the action of ethylene production (Sisler and Serek, 1997). Decreased ethylene production following 1-MCP exposure was consistent with results reported for many climacteric fruit such as apricots and plums (Dong *et al.,* 2002) and 'Red Delicious' and 'Granny Smith' apples (Fan and Mattheis, 1999a, b). In

addition, Jiang and Joyce (2002) showed that while 1 μL.L^{-1} was sufficient to decrease ethylene production in intact and cut apples, 10 μL.L^{-1} further reduced ethylene production. The effectiveness of 1 μL.L^{-1} 1-MCP to inhibit ethylene production indicated that sufficient concentration is necessary in order to bind enough receptors to block the production of ethylene. The suppression of ethylene might occur at certain enzymatic level, since Nakatsuka *et al.* (1977) reported that 1-MCP inhibited ethylene production in ripening tomatoes by strongly inhibiting the normal increase in activity of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase during ripening.

The treatment to reduce the production of ethylene was often associated with a lower respiration rate Bower *et al.,* 2003). The experiments in the current study showed that application of 1-MCP to intact tomatoes before slicing reduced the respiration rate of the slices. Similar results have been reported in intact tomatoes by Wills and Ku (2002) and Colelli *et al.* (2003) and on other fruits such as apricots and plums Dong *et al.,* 2002), banana (Jiang *et. al.* 1999) and peach (Mathoko *et al.,* 2001). Fan and Mattheis (2000) reported that respiration was inhibited in 1-MCP-treated broccoli by concentrations as low as 0.01 μL.L^{-1}. The 1-MCP treatments had also been found to reduce respiration rates in pineapple slices (Budu and Joyce, 2003). These results confirm the inhibitory role of 1-MCP on respiration rate.

Slice softening is a ripening process which influenced by ethylene. Treatments of 1-MCP to intact tomatoes retained the firmness of tomato slices during storage (Figure 2A and 5A). It was obvious that 1-MCP had a positive effect on slice firmness from the first day (day 1). Figures 2A and 5A clearly showed that there was a significant difference in firmness between slices from treated fruits and the control. As the change pattern in firmness was similar in all experiments, this indicated that the 1-MCP tratments affected firmer slices during storage. This may be due to 1-MCP slowing ethylene damage caused by "wound-ethylene" when the 1-MCP was applied prior to slicing. The significantly greater effect of 1-MCP on pericarp firmness when applied to intact fruit suggests that 1-MCP was able to block the ethylene receptors sites prior to cutting. Therefore, attempting to prolong the postharvest life of slices by applying 1-MCP after cutting was not likely to provide the sufficient benefit to quality. Treating intact tomato fruit with 1-MCP before slicing would be easily adapted by users in the fresh-cut industry.

The marketability of fruit slices was associated with an optimum level of firmness (Bolin and Huxoll, 1989; Mastrocola *et al*., 1995). The effect of 1-MCP on delaying softening of horticultural products during ripening seems to be a general effect of 1-MCP as it has been continuously observed. Moretti *et al.* (2001) found that whole tomatoes treated with 1 μL.L $^{-1}$ 1-MCP were significantly firmer than untreated fruits after 12 days storage at 20 °C. These results were also supported in studies by Jiang *et al.* (1999) and Jeong *et al.* (2002), who observed that 1-MCP retarded softening of banana fruit and avocado, respectively. In fresh-cut products, Jiang and Joyce (2002) also found better maintenance of firmness in apple slices when the intact apples were treated with 1-MCP before slicing.

The most effective concentration of 1-MCP for inhibiting the ethylene-induced softening of tomato slices was 1 μL.L^{-1}. This 1-MCP concentration was close to the reports of Jiang and Joyce (2002) for fresh-cut apples treated with 1-MCP at 1 to 10 μL.L^{-1} for 6 h at 20 °C which showed reduced respiration and ethylene production rates and delayed softening (better firmness maintenance) and delayed colour changes. Budu and Joyce (2003) showed that the application of 1- MCP at higher concentrations (up to 5 μL.L^{-1}) reduced the respiration rate and maintained the colour of fresh-cut pineapple pieces.

It was well known that only small amount of 1-MCP was necessary to inactivate the ethylene receptor (Sisler and Serek, 1997). However, it had been shown by many workers that the effectiveness of 1-MCP increased to a certain level of concentration after which there was no further increase, as indicated in banana (Jiang *et al.* 1999), avocado (Feng *et al.,*2000), mango (Jiang and Joyce, 2000), strawberry (Jiang *et al.,*2001), and plums (Salvador *et al.*2003). The current experiment using tomato indicated that 1 μL.L^{-1} 1-MCP was sufficient to obtain the highest response in most quality parameters. Therefore from two different experiments conducted during the study, it seemed that application of 1-MCP (1 μL.L^{-1} for 12 h at 20 °C) to intact tomatoes had shown a useful mean to reduce loss of quality in stored tomato slices. The 1 μL.L^{-1} concentration is equal to the current maximum registered dosage of 1-MCP for food (1 μL.L^{-1}) in the United States (Kubo *et al.,* 2003).

Despite the quantitative decrease in ethylene production, respiration rate and the delay in softening with increasing 1-MCP concentration, there were no differences in soluble solids concentrations within the 0.1-10 μL.L^{-1} 1-MCP range tested. This was consistent with other research on intact ripe tomatoes by Wills and Ku (2002) and breaker stage tomatoes by Moretti *et al.* (2001). They found out 1-MCP had no significant effect on soluble solids concentrations. Similarly, there were no significant changes in soluble solids content in oranges (Porat *et al.,* 1999) after application of 1-MCP. These studies suggested that the metabolism of sugar was not affected by 1-MCP.

In contrast, fruit treated with 1-MCP had higher titratable acidity, which meant 1-MCP could maintain high acidity. This is consistent with the results of Wills and Ku (2002) who applied 1-MCP to 'green' or 'ripe' intact tomato. They found that the higher the 1-MCP concentration, the higher the titratable acidity value. The incrtease value of titratable acidity in slices treated with 1-MCP was due to 1-MCP inhibition to the loss of acidity rather than stimulating acid production (Wills and Ku, 2002). Another explanation was that the retention of titratable acidity level by 1-MCP could be associated with the reduction of respiratory process (Figure. 1B).

CONCLUSION

The compound of 1-MCP has inhibitory effects on ethylene production in tomato slices products. The ripening processes of the slices treated with 1-MCP leading to softening and loss of titratable acidity were delayed or inhibited by 1-MCP application. The firmness of sliced tomatoes treated with 1-MCP was still

stable up to 10 days storage, while controlled sliced tomatoes showing significant slice softening. Consequently, the storage life of tomato slices could be extended by application of 1-MCP to intact tomatoes. The optimal concentration of 1-MCP was 1 $\mu L.L^{-1}$.

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