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Full Length Research Paper

Effect of 1-methylcyclopropene on the antioxidant capacity and postharvest quality of tomato fruit

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Tomato fruits '1402' were harvested at mature green (MG), light pink (LP) and light red (LR) stages and treated with 0.3 µL L^{-1} of 1-methylcyclopropene (1-MCP) at 20°C for 24 h to investigate the ability to retard tomato fruit ripening. The treated and control fruit were stored at 5°C and 12 °C for 14 days and a further 4 days at 20°C for a shelf life period. The results show that the effects of 1-MCP on fruit ripening were related to the stage of maturity and storage temperature. The MG stage was the optimal stage for 1-MCP treatment when fruit storage was at 12°C. 1-MCP treatment reduced the lipophilic antioxidant activity (LAA) of the tomato fruit, but the hydrophilic antioxidant activity (HAA) remained similar to that observed at harvest. 1-MCP is a potential tool for extending shelf life, delaying tomato fruit ripening (slowing color development and firmness loss) and enhancing quality of tomatoes.

Key words: Tomato, 1-MCP, storage, stage of maturity, temperature.

INTRODUCTION

Tomato fruit has a rather short post-harvest life. Temperature is the most important environmental factor in the postharvest life of tomatoes because of its dramatic effect on the rates of biological processes (Mostofi and Toivonen, 2006). However, tomato fruit cannot be stored at the low temperatures necessary to slow ripening because of chilling injury susceptibility (at temperature below 10°C). The ripening process in tomato fruit, as in other climacteric fruit, is highly dependent on ethylene action (Alexander and Grierson, 2002). Physiological changes associated with tomato fruit ripening can be halted or delayed by inhibiting ethylene perception, even when the fruit has reached advanced stages of ripening (Hoeberichts et al., 2002). Therefore, the control of ethylene production and action is an important component in postharvest management. 1-Methylcyclopropene (1-MCP) is a cyclic alkene (Sisler and Serek, 2003), an ethylene antagonist that binds to ethylene receptors in the plant cell and prevents ethylene from binding, thereby inhibiting ethylene signal transduction and action (Lurie, 2005). 1-MCP a gaseous ethylene binding inhibitor, has been useful in protecting tomato fruit from exogenous and self-produced ethylene, increasing their postharvest life and providing more flexibility during storage, distribution and retail (Watkins, 2006) and so 1-MCP is of great potential benefit. The application of 1-MCP delayed ripening and retarded color development (Moretti et al., 2001) without loss of development of sugars (Phasey et al., 2007) and increase in ripening index TSS/TA ratio (Guillen et al., 2007). The extent of inhibition depends on the duration of application, and the stage of fruit ripeness at treatment (Hoeberichts, 2002; Wills, 2002; Mir et al., 2004), while the effective concentration varies between cultivars (Watkins, 2006). The ripening process in tomato can be inhibited (with 1-MCP treatment) both on a physiological and molecular level, even at very advanced stages of ripening (Hoeberichts et al., 2002). According to Mostofi et al.

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(2003), the storage temperature after treatment significantly affects the color development of tomatoes treated with 1-MCP at the mature green stage. However, there is not much available literature about the effectiveness of 1-MCP in relation to the stage of ripening at harvest. 1-MCP delayed the ripening of tomato at higher storage temperature at green mature (stored at 30.5±1°C) and breaker (stored at 25±1°C) stages (Paul et al., 2010). Fruit treated at pink and light red stages ripened properly after a delay (Hurr et al., 2005), while 1-MCP treatment of red ripe fruit extended the shelf life with only one day (Ergun et al., 2006). 1-MCP is most effective at delaying ripening of mature-green tomatoes when they are stored near the currently recommended temperature range of 12.5 to 15.8°C (Mostofi et al., 2003). Therefore, slow ripening varieties should be treated with 1-MCP either at breaker or turning stages so that the fruits can achieve the acceptable organoleptic characteristics. It was reported by Huber (2008) that recovery of ripening characteristics and attainment of optimum quality for climacteric fruits are best achieved if 1-MCP is applied after the initiation of ripening.

The objective of this work was to investigate the ability of 1-MCP to retard ripening and quality changes of tomato fruit harvested at the three maturity stages (mature-green, light-pink and light-red) and at two different storage temperatures (5 and 12°C).

MATERIALS AND METHODS

Tomato (*L. esculentum* Mill.) cv. 1402 (Hazera Genetics, Ltd, Israel; VF_2TmN) is a commercial cultivar for greenhouses during the fall, winter and spring. Fruit of uniform size, about 180 g, were picked directly from a commercial unheated plastic house in the central part of Israel at the three maturity stages: mature-green (MG); light pink (LP) and light red (LR). The soil condition was well drained and sandy, and drip irrigation was used. Cultural practices, such as land preparation, planting and plant protection for the crop, were as is the standard in this area. Fruit without defects or diseases, were harvested with a calyx, same size, shape and injury free were selected for the experiment.

1-MCP application

1-MCP was applied on the day of harvest to three replicate units of fruit for each stage of maturity. 1-MCP powder (0.14% a.i. SmartFresh^{TM}) was placed in a 1-MCP applicator equipped with a fan to generate and uniformly distribute concentrations of 300 nL·L^{-1}. Fruits were placed inside a 250 L chamber that was tightly sealed for 24 h at 20°C and 85% relative humidity (RH), immediately after application of 1-MCP. Control fruits were kept under identical conditions without 1-MCP treatment.

Storage conditions

After, treatments fruit were stored for 14 days at 5°C or at 12°C and 90% RH in the dark. For each stage of maturity and storage temperature regime, 20 fruits per replicate were sampled for analysis. After 14 days storage at either temperature, fruit were transferred to 20°C to study their shelf life. Analyses were performed after four days at 20°C.

Quality parameters

Fruit firmness was measured with a durometer (Shore Instrument and Mfg. Co., Jamaica, NY, USA) on two opposite sides of each fruit. Firmness was expressed as units of firmness (UF). A fruit was considered very firm with UF > 45; firm with UF = 36 to 45; soft with UF = 26 to 35; very soft with UF < 25. For chilling injury (CI), a fruit with a sunken pitting of more than 2 mm on the skin or calyx was considered as a damaged fruit. CI was expressed as a percentage of damaged fruits from the total initial fruit number.

Changes in the overall external appearance were evaluated by a jury of five persons as: 1, unusable; 2, poor; 3, salable; 4, very good; 5, excellent. Defects (green sholders) or other discoloration were scored on a 1 to 5 scale, where 1 is none, 2 is slight defect but product salable (<10% fruit with green shoulders), 3 is moderate, product useable but not salable (10 to 30% fruit with green shoulders), 4 is moderately severe (30 to 50% fruit with green shoulders) and 5 is severe and unusable (≥50% fruit with green shoulders).

Color was measured with a Chroma-Meter (Minolta, Ramsey, NJ, USA) that was calibrated against a white standard tile. Two opposite sides of each tomato were measured and the results were expressed as Hue angle ($\tan^{-b/a}$). Total soluble solids (TSS) were measured with a digital refractometer (Atago, Japan) in juice prepared from fresh tissue. The titrable acidity (TA) was measured with 5 ml aliquots of juice that were titrated to pH 8.1 with 0.1N NaOH (required to neutralize the acids of tomatoes in phenolphthalein presence) and the results were expressed as percentage of citric acid . Decay was expressed as a percentage of infected fruit relative to the total initial fruit number.

Antioxidant activity: extraction and determination

The antioxidant activity was measured using a modified version of 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonate (ABTS) discoloration method by Vinokur and Rodov (2006). Hydrophilic and lipophilic fractions were isolated from fresh samples, without preliminary drying, by stepwise extraction with acetate buffer, acetone and hexane and repeated partition of water-soluble and water-insoluble portions. The antioxidant activity was evaluated by discoloration of the $ABTS^+$ radical cation. The radical was generated in acidified ethanol medium in order to allow for measurements of the activities of both hydrophilic and lipophilic antioxidants. The final reaction mixture contained 150 µM (ABTS) and 1.77 mM 2,2′-azobis(2-amidinopropane) dihydrochloride (AAPH) in acidified ethanol (249 ml ethanol 99.9% plus 250 µl H_2SO_4). Incubation of the reaction mixture at 45°C for 60 min was sufficient for $ABTS^+$ generation. The obtained stock solution of $ABTS^{+\cdot}$ can be stored for at least two days at 4°C without significant loss of its properties. The decolouration test was performed in plastic cuvettes by adding 10 µL of test sample to 1 mL of acidified ethanolic solution of $ABTS^{+\cdot}$ and comparing the optical density at 734 nm after 15 min of incubation at room temperature with that of a blank sample. Final results were calculated using the comparison between the absorbance of the samples and the absorbance of the standard (±)-6-Hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox).

The antioxidant levels in the samples were determined as trolox equivalents (TE) according to the formula $TE = (A_{sample} - A_{blank})/(A_{standard} - A_{blank}) \times C_{standard}$; where, A is the absorbance at 734 nm and C is the concentration of the trolox (mM). In order to calculate the trolox equivalent antioxidant capacity (TEAC) per weight of plant tissue we used the formula: TEAC (mmole TE/mg) = (TE × V)/(1000 × M), where, V is the final extract

Table 1. Effect of fruit maturity and 1-MCP application on quality attributes of tomato fruit after 14 days storage at 5 and 12°C followed by four days at 20 °C (shelf life).

T °C	Stage of maturity	TSS (%)	Firmness (UF)*	Decay (%)**	Defects (1-5)$^{+}$	*E. apperian* (1-5)$^{++}$	Chilling injury (%)
To: Immediately after harvest							
	MG	4.2±0.2^{d}	46±0.5^{a}	0^{d}	1^{e}	2.5^{d}	
	LP	4.3±0.3^{c}	43±0.5^{a}	0^{d}	1^{e}	4.0^{a}	
	LR	4.4±0.2^{b}	39±0.5^{b}	0^{d}	1^{e}	4.2^{a}	
1-MCP (1-methylcyclopropene)							
	MG	4.3±0.5^{c}	45±1^{a}	0^{d}	5^{a}	2.0^{e}	-
5°C	LP	4.5±0.2^{a}	43±1^{a}	0^{d}	4^{b}	3.0^{c}	-
	LR	4.5±0.3^{a}	38±1^{b}	5^{c}	3^{c}	3.0^{c}	-
	MG	4.4±0.3^{b}	44±1^{a}	0^{d}	1^{e}	4.0^{a}	-
12°C	LP	4.3±0.3^{c}	38±1^{b}	0^{d}	1^{e}	3.5^{b}	-
	LR	4.5±0.4^{a}	32±2^{c}	10^{c}	1^{e}	2.5^{d}	-
Control							
	MG	4.3±0.5^{c}	42±1^{a}	5^{c}	3^{c}	3.5^{b}	-
5°C	LP	4.4±0.3^{b}	37±1^{b}	0^{d}	2^{d}	3.3^{b}	-
	LR	4.4±0.3^{b}	33±2^{c}	30^{b}	2^{d}	1.8^{e}	-
	MG	4.2±0.4^{d}	38±1^{b}	5^{c}	1^{e}	3.0^{c}	-
12°C	LP	4.2±0.4^{d}	32±2^{c}	5^{c}	1^{e}	2.3^{d}	-
	LR	4.5±0.6^{a}	27±2^{d}	40^{a}	1^{e}	1.2^{f}	-

MG, mature-green; LP, light pink; LR, light red; TSS, total soluble solid; *F, firmness (expressed as units of firmness; UF). Fruit was considered very firm with UF>45; firm with UF 36 to 45; soft with UF 26 to 35; very soft with UF <25. **Decay (*Alteraria i Botrytis*); $^{+}$defects (green shoulders) or other discoloration were scored on a 1 to 5 scale, where 1 is none, 2 is slight defect but product salable (<10% fruit with green shoulders), 3 is moderate, product useable but not salable (10 to 30% fruit with green shoulders), 4 is moderately severe (30 to 50% fruit with green shoulders) and 5 is severe, unusable (>50% fruit with green shoulders). $^{++}$External appearance: 1, unusable; 2, unsalable; 3, salable; 4, good; 5, very good. Different letters indicate significant differences at $P < 0.05$ (Tukey's test).

volume and M is the amount of tissue that was extracted.

Carotenoid content

Carotenoids were determined in the lipophilic fraction (Vinokur and Rodov, 2006) by extracting four times with 3 ml of hexane (total of 12 ml) and drying under nitrogen. The sample was re-suspended in 2 ml of 100% acetone and the absorbance measured in a spectrophotometer (IRMECO QmbH, Germany, Model U2020) at 470, 645, and 662 nm.

Chemical reagents

All chemicals (unless otherwise mentioned) were purchased from Sigma-Aldrich, St. Louis, MO, USA, and were of analytical grade.

Statistical analysis

Experiments were performed according to a factorial design. The results obtained in each analysis described previously were treated by analysis of variance followed by Tukey's test, using the software Statistica 6.1 (Statsoft, Tulsa, OK, USA). All analyses were performed with a 95% confidence level ($p<0.05$).

RESULTS AND DISCUSSION

Total soluble solids

During maturation and ripening of fruit, there were changes in total soluble solid (TSS). TSS was found to increase in tomato with gradual advancement of time, irrespective of maturity stage (Moneruzzaman et al., 2008). In our study, fruit TSS after 14 days storage at 5 and 12°C followed by four days at 20°C was higher in fruit harvested at the light red stage than in fruit harvested at mature green stage. This pattern in TSS associated with maturity was not affected by 1-MCP treatment (Table 1). This statement can be confirmed by the results presented by Moretti et al. (2002), Wills and Ku, (2002) and Mir et al. (2004).

Firmness

The firmness of three different maturity stages of control and 1-MCP-treated tomatoes was assessed on alternate days for 14 days after harvest. The firmness of LR stage

untreated control fruit decreased most rapidly and reached 25-30 UF on day 14 at 12°C, particularly during the shelf-life period (4 days at 20°C). The MG stage was the optimal stage for 1-MCP treatment to delay fruit ripening; the treated fruits being firmer (45UF) than those treated at later maturity stages. 1-MCP-treated fruit did not soften appreciably until day 14 (Table 1). Firmness of 1-MCP treated mature green fruit (at 18 days) was higher than that of the mature green control (at 18 days), which is to be expected given that controls would ripen at this time.

However, when 1-MCP was applied at the mature green stages (especially when followed by storage at 5°C), the fruits showed a long delay in the development of color and showed a high percent of defects; did not soften sufficiently, shriveled and were susceptible to disease. The trend of maintaining firmness in response to 1-MCP was reported for mature green, breaker, and turning 'Florida 47' tomato fruit treated with 1-MCP (Hurr et al., 2005), and was also evident from the data for 1-MCP-treated breaker Roma-type tomato (Mir et al., 2004). In other studies, it was shown that 1-MCP can delay ripening but does not significantly alter the firmness (Mostofi et al., 2003).

Decay

Maturity stage of the fruit at the time of 1-MCP treatment affects the susceptibility of the fruit to disease. The shelf life of light red-harvested tomatoes was limited, as a long storage period leads to a decrease in firmness, an increase in decay development and causes a moldy smell. In light red tomato with 1-MCP treatment, we observed 10% decay fruit in comparison with 30% decay in the control fruits (without 1-MCP) after two weeks storage at 5°C plus 4 days at 20°C (shelf life). Similarly, trends in reducing decay with 1-MCP were observed also at the higher storage temperature (12°C).

There were no benefits for 1-MCP treatment for fruit at all stages when stored at 5°C, apart from some higher firmness for LP and LR fruit (Table 1). Guillen et al. (2006) reported lower decay of tomatoes due to 1-MCP treatment. Sensitivity of tomatoes to rot was however found to be variable (13 to 40%) depending upon the cultivar and ripening stage at 28 days after harvest, at a storage temperature of 10°C. Paul et al. (2010) obtained comparable results with 5 to 60% decay in the control in contrast to 2 to 30% of the treated fruit after 26 days' storage at 25°C. In some cases, mature green and breaker stage fruits shriveled and developed decay before ripening, although fruits treated at pink and light red stages ripened properly after a delay (Hurr et al., 2005). Díaz and Batal. (2002) found that treatment with 1-MCP increased susceptibility of tomatoes to *Botrytis cinerea*. Another study suggested that the use of 1-MCP reduced tomato decay at green or pink stages caused by *Alternaria alternata*, *B. cinerea*, and *Fusarium* spp. (Su-Hai and Daglas, 2011). There are also numerous cases where 1-MCP treatment has been shown to be beneficial and prevent fruit decay (Guillen et al., 2005).

Color development

Harvest maturity determined by color is important when considering a postharvest application of 1-MCP. Fruit treated at the mature green stage did not ripen as uniformly as fruit treated at more mature ripening stages. In some cases, color development started first at the stem end and then gradually shifted to the blossom end. Fruit of light red maturity were the least affected by 1-MCP treatment. After the shelf-life period, all tomatoes developed a similar color although they were harvested at different stages of maturity, with average H^o value generally close to 40°, except for the 1-MCP mature green fruits stored at 5°C that had a higher H° value (56 degrees). Both ripening stage and 1-MCP application affected the shelf-life of tomatoes (Figure 1).

Pigment synthesis and expression has been shown to be delayed when 1-MCP was applied at early stages of maturity (Moretti et al., 2001). Later maturities were demonstrated to be less affected by 1-MCP treatment (Ergun et al., 2006). This is in agreement with the results of Harris et al. (2000) who showed that the effectiveness of 1-MCP varied with respect to fruit maturity. Results obtained from Mostofi et al. (2003) suggest that tomato color development is affected by temperature at the time of treatment. Fruit stored at 15°C had a three times longer period in color initiation than the other two temperatures (20 and 25°C). 1-MCP treated fruit reached lowest hue angle values (~45°) for optimum ripeness 12 days later than the control fruit (Mostofi et al., 2003). These results suggest that 1-MCP treatment is clearly effective in delaying the rate of color development.

Carotenoid content

The trends observed for color (H^o angle) were similar to those for total carotenoids. Uneven red color development in individual fruits treated with 1-MCP was observed at the early stage of ripening. Total carotenoids increased during storage from an initial level of 115 µg g^{-1} D.M in MG tomato at time 0, and reached their highest level (800 µg g^{-1} D.M.) in LR fruits (control) kept for two weeks at 12°C plus four days at 20°C. This has been reported also by Goren et al. (2010) who found that the initial level of carotenoids at time 0 was about 230 µg g^{-1} D.M and about 700 µg g^{-1}D.M after the fruits had been kept at 20°C for nine days. Keeping fruits (included all stages of ripening) at 5°C with 1-MCP treatment significantly inhibited acumulation of carotenoids. After two weeks of storage, significant differences were

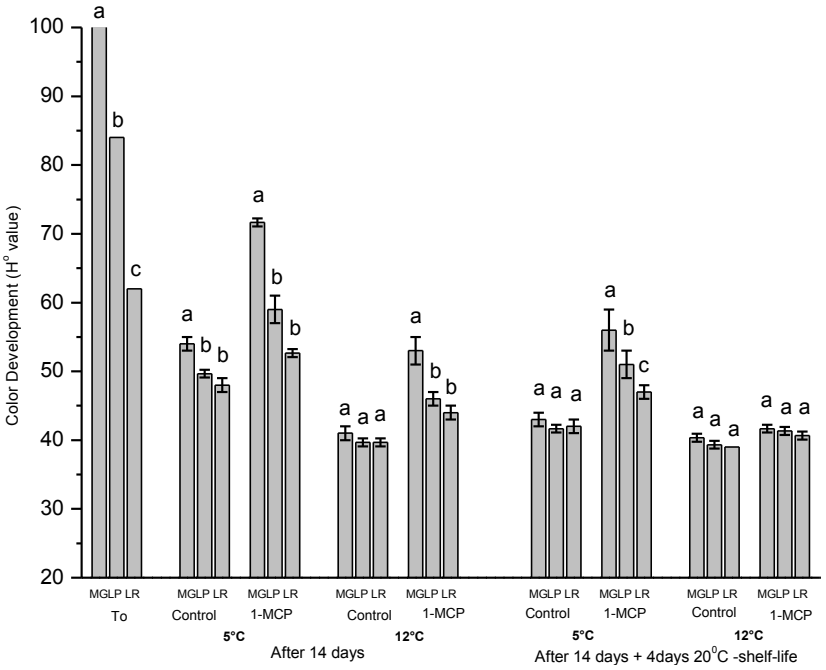

Figure 1. Color development of tomato fruits after 14 days storage at 5°C and 12°C + 4 days at 20°C (shelf life). To, immediately after harvest; different letters indicate significant differences at P < 0.05 (Tukey's test).

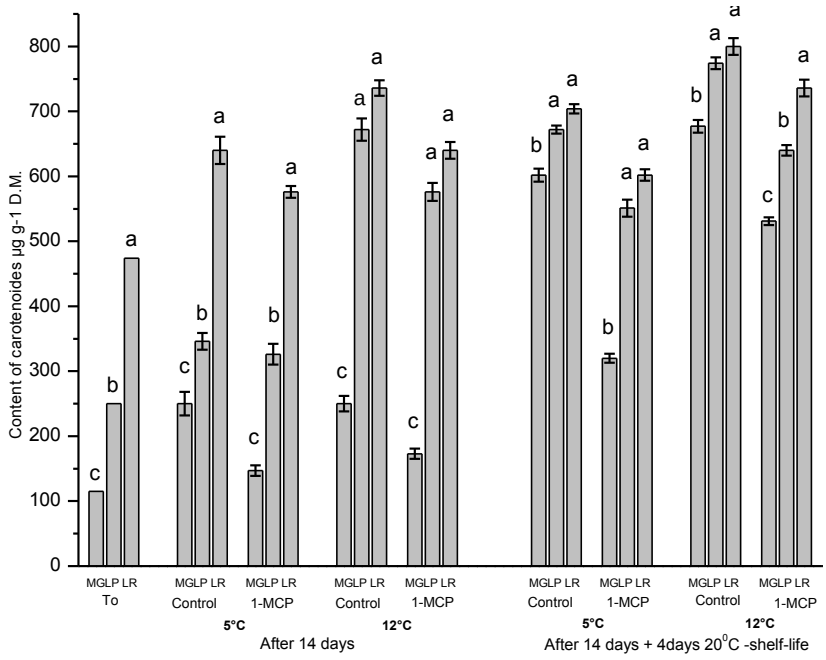

Figure 2. Carotenoids content of tomato fruits after 14 days storage at 5 and 12°C + 4 days at 20°C (shelf life).To, immediately after harvest; different letters indicate significant differences at P < 0.05 (Tukey's test).

observed in the carotenoid contents between different stages of maturity and also between different storage temperatures (Figure 2).

The lowest impact of 1-MCP on the accumulation of carotenoids was observed in fruit that were closest to full maturity, marked as 'light red'. At this stage of maturation,

Table 2. Effect of fruit maturity and 1-MCP aplication on antioxidant activity after 14 days storage at 5 and 12°C followed by 4 days at 20°C (shelf life).

T °C	Stage of maturity	Lipophylic LAA (µmol TE/g fresh weigh)	Hydrophilic HAA (µmol TE/g fresh weigh)	Total TAA (µmol TE/g fresh weigh)
To: Immediately after harvest				
	MG	0.31 ± 0.03^{f}	1.74 ± 0.08^{a}	2.05 ± 0.11^{d}
	LP	0.48 ± 0.04^{e}	1.77 ± 0.08^{a}	2.25 ± 0.12^{c}
	LR	0.72 ± 0.07^{cd}	1.80 ± 0.05^{a}	2.52 ± 0.17^{b}
1-MCP (1-methylcyclopropene)				
5°C	MG	0.60 ± 0.03^{d}	1.66 ± 0.05^{ab}	2.26 ± 0.14^{c}
	LP	0.59 ± 0.04^{d}	1.53 ± 0.03^{b}	2.12 ± 0.14^{d}
	LR	0.82 ± 0.08^{c}	1.56 ± 0.04^{b}	2.38 ± 0.18^{bc}
12°C	MG	0.74 ± 0.08^{cd}	1.56 ± 0.08^{b}	2.30 ± 0.29^{a}
	LP	1.25 ± 0.11^{b}	1.62 ± 0.03^{ba}	2.87 ± 0.27^{b}
	LR	1.33 ± 0.10^{b}	1.73 ± 0.05^{a}	3.06 ± 0.24^{ba}
Control				
5°C	MG	0.94 ± 0.05^{c}	1.53 ± 0.06^{b}	2.47 ± 0.17^{b}
	LP	0.96 ± 0.08^{c}	1.53 ± 0.03^{b}	2.49 ± 0.22^{b}
	LR	1.31 ± 0.12^{b}	1.77 ± 0.05^{a}	3.08 ± 0.24^{a}
12°C	MG	1.14 ± 0.10^{b}	1.49 ± 0.05^{b}	2.63 ± 0.26^{b}
	LP	1.52 ± 0.12^{a}	1.72 ± 0.07^{a}	3.24 ± 0.29^{a}
	LR	1.68 ± 0.15^{a}	1.74 ± 0.06^{a}	3.42 ± 0.32^{a}

Control, without 1-MCP application. Different letters indicate significant differences at P<0.05 (Tukey's test). Values are mean ± standard deviation (n=3).

almost no difference was noted in the accumulation of carotenoids in fruits, regardless of 1-MCP treatment. The same result was observed with regards to temperature, with no difference found in carotenoid levels in fruit kept at 5 or 12°C. Carotenoid accumulation in fruit at all stages of maturity was significantly delayed by 1-MCP treatment. This is in agreement with (Wang et al., 2010) who showed that the effectiveness of 1-MCP also inhibited the lycopene accumulation and chlorophyll degradation. At the end of the storage period, the control fruit contained around 153% and more total carotenoids than the fruit treated with 1-MCP.

The storage temperature of 5°C after 1-MCP treatment blocked the color development of tomatoes at the mature green stage. An effective dose of 1-MCP (0.3 µL L^{-1} for 24 h) was obtained from this study which can delay the ripening of tomato fruits stored at 12°C at all stages of maturity. Under certain 1-MCP treatment conditions, tomato cultivars have experienced uneven color development. This condition was noticed at the early maturity stage and early stages of ripening, where degreening started at the blossom end of the tomato during the ripening period.

Antioxidant activity

After two weeks of storage at 5°C and four days shelf life at 20°C, the total antioxidant activity (TAA) slowly increased and reached a content of 2.48 in MG fruit, 2.50 in LP fruit and 2.62 µmol TE/g fr.wt. in LR fruit. This was mainly due to changes in the lipophilic antioxidant activity-LAA, depending on the stage of maturity (MG 0.94, LP-0.96 and LR-1.31 µmol TE/g fr.wt). The hydrophilic antioxidant activity, HAA, remained practically unchanged compared to the activity at the beginning of storage (Table 2).

The antioxidative system plays a fundamental role in the ripening of tomato fruits (Jimenez et al., 2002). Changes in the TAA is measured as the sum of the hydrophilic and lipophilic antioxidant activities. The hydrophilic antioxidant activity represents 71 to 85% of the total antioxidant activity, with the lowest percentage contribution being observed in the last stage of ripening (Cano et al., 2003). The hydrophilic antioxidant activity (HAA) is significantly higher than the lipophilic antioxidant activity (LAA), both immediately after harvest and after storage (Goren et al., 2010). TAA in MG fruit immediately after harvest was 2.05 (0.31 LAA and 1.74 HAA) µmol TE/g fr.wt, in LP ripening stage was 2.25 (0.48 LAA and 1.77 HAA) and in LR stage TAA was 2.52 (0.72 LAA and 1.80 HAA). In tomatoes, the ratio of lipophilic to hydrophilic AA changed from approximately 1:5 in mature green fruit to 1:3 in light pink fruit and 1: 2.5 in light red fruit.

After two weeks storage at 5°C and four days shelf life at 20°C, total TAA slowly grew up and the obtained content were 2.48 in MG fruit, 2.50 in LP fruit and 2.62 µmol TE/g fr.wt. in LR fruit (Table 2). All the antioxidant

activity in strawberry for example, is represented by hydrophillic compounds with just trace amount of lipophilic antioxidants (Vinokur and Rodov, 2006).

In tomato fruits stored at 12°C, the total activity increased most probably due to the accumulation of carotenoids, especially after shelf life (4 days on 20°C). After storage, the ratio between hydrophilic and lipophilic activity changed from 1:1.5 in MG fruit to 1:1 in light red fruit. In the present study, mature green fruits treated with 1-MCP in cold storage (5°C) did not develop good sensory attributes, their color remained pink, and carotenoids contents and antioxidant activity were low. These fruits exhibited very high 'green' notes (unripeness). Collectively, our data indicate that 1-MCP causes minor shifts in the quality attributes of locule color relative to external color, which may reduce the value of this treatment, but benefits accrued by slowed firmness loss and color development may afford sufficient compensation to make 1-MCP application commercially feasible. These results suggest that 1-MCP can be used as a commercial technology due to its ability to maintain antioxidant capacity of tomato fruit as well as to delay fruit ripening.

Conclusion

This study found that an effective dose of 1-MCP (0.3 nL L^{-1} for 24 h) can delay the ripening of tomato fruits. Tomato fruits at the mature green stage kept at 5°C could not obtain adequate ripening and quality attributes. This was due to too low temperature storage with the additional impact of 1-MCP in inhibiting the ripening process and led to visible defects in the form of green shoulders. Shortcomings in the form of greenish shoulder around the stem scar (in 70% of fruits) reduced the visual attractiveness of the fruits. Ripening stage and temperature of storage affects the shelf-life of 1-MCP treated tomatoes.The mature green stage was the optimal stage for 1-MCP aplication when fruit was stored at 12°C. However, the effects of 1-MCP on nutritional compounds and antioxidant activity of tomato fruits are still unclear, and need to be more precisely determined.

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