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Research Report

Effects of an Ethylene Absorbent and 1-Methylcyclopropene on Tomato Quality and Antioxidant Contents during Storage

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Abstract. We compared the effects of an ethylene absorbent and the ethylene inhibitor 1-methylcyclopropene (1-MCP) on tomato (*Solanum lycopersicum* Mill. cv. Dotaerang) during storage. Tomato fruits at the 'breaker' stage were harvested and treated with an ethylene absorbent, 1 $\mu L \cdot L^{-1}$ 1-MCP or 2 $\mu L \cdot L^{-1}$ 1-MCP and stored at 20°C for 15 days. We then measured weight loss, peel color, firmness, soluble solids content (SSC), titratable acidity, pH, ethylene production and total phenolic and flavonoid contents in the fruits. Color development occurred more rapidly in the control than in fruits treated with the ethylene absorbent or 1-MCP (1 $\mu L \cdot L^{-1}$ and 2 $\mu L \cdot L^{-1}$) on day 6 and 9. The Hunter a value (redness) of 1-MCP (2 $\mu L \cdot L^{-1}$)-treated fruit on day 6 was 2.24 ± 3.8, while that of the control was 13.39 ± 2.23, indicating that color development was delayed by 1-MCP treatment (2 $\mu L \cdot L^{-1}$ was more effective than 1 $\mu L \cdot L^{-1}$). Ethylene absorbent treatment was not more effective at maintaining fruit firmness than 1-MCP (2 $\mu L \cdot L^{-1}$) treatment. There was no statistically significant difference in fruit firmness between the ethylene absorbent treatment group and the control. Total phenolic and total flavonoid contents increased in all treatment groups during storage. These contents did not significantly differ among groups on day 15. These results suggest that 1-MCP treatment is highly effective in delaying tomato ripening during storage and that 2 $\mu L \cdot L^{-1}$ 1-MCP treatment is more effective than 1 $\mu L \cdot L^{-1}$ treatment. However, the ethylene inhibitor did not influence the levels of antioxidant compounds compared with the control.

Additional key words: flavonoid, phenolic, physicochemical, *Solanum lycopersicum*

Introduction

Tomatoes are one of the most widely cultivated vegetables worldwide. Tomato fruits contain many bioactive compounds, such as vitamin C, carotenoids, flavonoids and lycopene (Khachik et al., 2002; Rao et al., 1998), as well as glucose, fructose and citric acid (Davies and Hobson, 1981). Tomatoes are climacteric fruits that show dramatic increases in respiratory rates and ethylene production during the ripening stage, as do apples and bananas (Watkins, 2006). It is quite difficult to maintain the quality of these products due to high ethylene production and softening of the fruit. Therefore, maintaining the freshness of these fruits by inhibiting ethylene production is highly important, as tomatoes are consumed, distributed and exported as fresh fruits. Tomatoes are usually harvested at the immature stage to avoid physical damage and to extend shelf life, and they are allowed to ripen during distribution or storage (Wills and Ku, 2002).

Ethylene is a plant hormone that is responsible for physiological changes in fruits after harvest. In particular, ethylene affects the maturation of fruit tissue and the yellowing of leafy vegetables, including senescence. The production of ethylene in plants occurs when 1-aminocyclopropane-1-carboxylic acid (ACC) is oxidized by ACC oxidase during the methionine cycle (Wang et al., 2002). Direct absorption by porous activated carbon, with high absorbent properties, can be used to inhibit the production of ethylene. Potassium permanganate ($KMnO_4$) immobilized on porous material can also be used as an absorbent to oxidize ethylene and to reduce the material to manganese dioxide (MnO_2). Several recent studies have investigated the use of ethylene inhibitors, such as silver thiosulfate (STS) and 1-MCP, to inhibit ethylene production (Kim et al., 2010; Yun and Lee, 1996).

The inhibitor 1-MCP irreversibly binds to ethylene receptors, inhibiting ethylene activity and senescence in horticultural crops (Sisler and Blankenship, 1996). Many studies have confirmed the effect of 1-MCP treatment on the maintenance of freshness in apples, avocados, bananas, pears and tomatoes (Watkins, 2006). In Korea, extensive research has been conducted on the use of this inhibitor in apples, sweet persimmons, peaches and tomatoes (Choi and Bae 2007; Choi 2010; Chun et al., 2010; Park et al., 2011). However, most of these studies have focused only on physicochemical characteristics of fruits, such as color, firmness and acidity, as well as ethylene production rates and respiratory rates. Further research is needed on the effects of ethylene absorbents and 1-MCP on nutritional factors in fruit, particularly antioxidants.

Commercialization of 1-MCP to inhibit ethylene production and to maintain freshness in fruits and vegetables is currently underway in Korea. Nevertheless, the application of 1-MCP is limited to apples, pears and sweet persimmons in Korea, which require long-term storage facilities. Since 1-MCP generators are only suitable for fruit storage, a high degree of sealing is necessary after 1-MCP application. However, fruits and vegetables, which require short-term shipment, are packed immediately after harvest and are distributed within the next few days. Therefore, since the application of 1-MCP is not a straightforward process, most of the commercial packages containing these fruits and vegetables in Korea are simply packed with an ethylene absorbent.

To circumvent this obstacle, a company has developed a 1-MCP generator for use in general fruit packaging during distribution beginning in 2013. This kit contains both a 1-MCP precursor and initiator in a glass tube, which can easily be mixed to produce 1-MCP, enabling application during the packaging process (Yoo and Jung, 2013) (Fig. 1).

The objective of this study is to investigate the effects of 1-MCP treatment on fruit quality attributes of tomatoes and the levels of antioxidant compounds, such as total phenolic compounds and flavonoids.

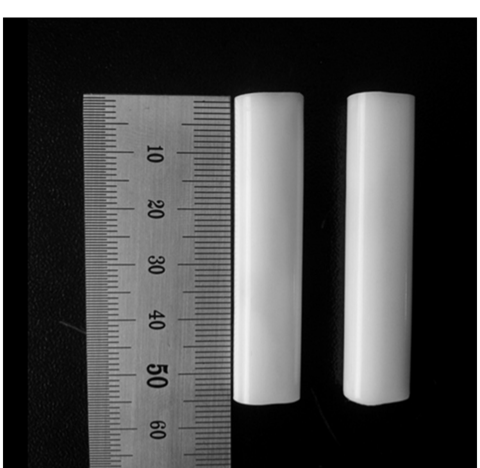

Fig. 1. Actual size and shape of 1-MCP kit.

Materials and Methods

Experimental Materials and Ethylene Inhibitor Treatments

Tomato fruits (*Solanum lycopersicum* Mill. cv. Dotaerang) were harvested in a greenhouse in Kyung-Ju city, Kyungsang-Buk-Do, South Korea on April 8, 2013. The samples were harvested at the 'breaker' stage, sorted to eliminate damaged fruit and selected for uniform size and color. An ethylene absorber (e-Fresh pack, Dongbu Farm Hannong, Korea) and 1-MCP kit (Erum Biotechnologies, Korea) were used for treatment. The ethylene absorber mainly consisted of $KMnO_4$, and 1 g of 1-MCP was used per 1 kg of vegetables (commercial usage amount). A 1-MCP kit (one kit generated 1 $\mu L \cdot L^{-1}$ concentration per 20 L space in a single cardboard box package) was used for the experiments at concentrations of 1 $\mu L \cdot L^{-1}$ and 2 $\mu L \cdot L^{-1}$. Cardboard boxes (20 L) filled with tomatoes were treated with the ethylene absorbent, 1 $\mu L \cdot L^{-1}$ 1-MCP or 2 $\mu L \cdot L^{-1}$ 1-MCP at 20°C. Each box was sealed with polyethylene (PE) film to increase the effects of the ethylene absorber and 1-MCP. After 24 h, the PE film was removed. To mimic standard distribution conditions, the fruits were stored at 20°C. Physical qualities, ethylene production rates and total phenolic and total flavonoid contents were analyzed at 3 days intervals. Ten fruits per treatment were used for the analysis, and all measurements were repeated three times.

Evaluation of Physicochemical Qualities

Lightness (L), redness (a) and yellowness (b) readings were taken using a colorimeter (Chroma Meter CR-400, Minolta, Tokyo, Japan). Three readings were taken around the equatorial region of each tomato and the average values were calculated. To observe the appearance and color changes in fruit during storage, a digital camera (EOS 550D, Canon, Tokyo, Japan) was used to take photographs daily. Fruit weights were also recorded, and the percentage weight loss after harvest was calculated.

Firmness was measured by performing a puncture test on each tomato with intact skin using a fruit hardness tester (FHM-1, Demetra, Tokyo, Japan) fitted with a 5.0 mm diameter probe. The titratable acidity (TA), soluble solids content (SSC) and pH of each tomato were measured after grinding the fruits in a blender (HR20011, Philips, NV, USA). The TA was measured in samples diluted in distilled water after adding phenolphthalein indicator and 0.1 N NaOH. The SSC of each sample was detected using a digital glucose refractometer (PAL-1, Atago, Tokyo, Japan). The pH was measured with a pH meter (Starter 300, Ohaus, NJ, USA) (Heo and Choi, 2006; Opiyo and Ying, 2005).

Measurement of Ethylene Production

To analyze the ethylene production rate, the tomatoes were placed in 9 L plastic sealed containers (Lock & Lock, Korea) for 4 h. The inner air (1 mL) was then sampled using a syringe to measure accumulated ethylene by gas chromatography (GC-2014, Shimadzu, Tokyo, Japan). The detector temperature was set at 200°C using helium as a carrier gas with a flow rate of 30 $mL{\cdot}min^{-1}$ (Choi and Bae, 2007; Wills and Ku, 2002).

Extraction of Antioxidants

To extract antioxidant compounds, frozen tomato samples were ground with a mortar and pestle in liquid nitrogen. Powdered tissue (25 g) was mixed with 80% acetone (250 mL) in a blender (HR20011, Philips, NV, USA) for 3 min and further homogenized with Polytron PT 10/35 (Brinkmann, MI, USA) at 10,000 rpm for 3 min. The crude mixture was filtered with Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator (N-1000, Eyela, Tokyo, Japan) and used for further analysis (Meyers et al., 2003; Shin et al., 2008).

Total Phenolic and Total Flavonoid Contents

The extracted samples were analyzed using the Folin-Ciocalteu colorimetric method to determine total phenolic contents (Meyers et al., 2003; Singleton et al., 1999). Distilled water (2.6 mL) and the diluted sample (0.2 mL) were combined in a 15 mL test tube. After adding Folin-Ciocalteu reagent (0.2 mL), the tube was vortexed and incubated for 6 min at room temperature. Then, 2 mL of 7% Na_2CO_3 was added and the sample was vortexed. The sample was then incubated in the dark at room temperature for 90 min. The absorbance at 750 nm was measured with a UV spectrophotometer (UV-1201, Shimadzu, Tokyo, Japan). The results were expressed as gallic acid equivalents (GAE) using a standard curve.

Total flavonoid contents were measured by colorimetric assay (Jia et al., 1999; Meyers et al., 2003). Distilled water (4 mL) and diluted sample (1 mL) were combined in a 15 mL test tube and vortexed after adding 0.3 mL of 5% $NaNO_2$. The sample was incubated for 5 min at room temperature, followed by the addition of 10% $AlCl_3$ (0.3 mL) and vortexing. After 6 min of incubation, 1 N NaOH (2 mL) and distilled water (2.4 mL) were added to the sample, which was then vortexed. Finally, the absorbance was measured at 510 nm with a spectrophotometer (UV-1201, Shimadzu, Tokyo, Japan). The results were expressed as (+) catechin equivalents (CE) using a standard curve.

Statistical Analysis

The data were subjected to one-way analysis of variance (ANOVA) using the SPSS program (IBM SPSS Statistics 20, SPSS Inc., USA) to determine main effects and interactions. Where appropriate, mean separation was accomplished using the Duncan's multiple range test at $p < 0.05$. Pearson correlations were used to quantify the relationships between parameters during storage. Ten fruits per treatment were used for analysis. The data are expressed as means ± standard deviation from triplicate determinations.

Results and Discussion

TA, SSC and pH

Higher TA on days 6, 9, and 12 was observed in samples treated with 1-MCP (2 $\mu L{\cdot}L^{-1}$) than in the control and ethylene absorbent treatments (Table 1). Several studies have shown that TA is higher in 1-MCP-treated tomatoes than in untreated fruits (Opiyo and Ying, 2005; Wills and Ku, 2002), and 1-MCP delays acidity loss in most fruits due to delayed ripening (DeEll et al., 2002; Wills and Ku, 2002).

The SSC and pH of tomatoes in the treatment groups and the control differed slightly during storage, but at the end of the storage period, the SSC in fruits treated with ethylene inhibitors was lower than that of the control (Table 1). However, Wills and Ku (2002) reported that the SSC of 1-MCP-treated tomatoes did not differ from that of the control during storage. Several studies have investigated the effect of 1-MCP treatment on sensory evaluation of tomato (Baldwin et al., 2011; Cliff et al., 2009; Wills and Ku, 2002). Wills and Ku (2002) concluded that the taste of 1-MCP-treated fruit was better than that of the control due to the higher SSC/TA ratio in 1-MCP treated fruit. However, the difference in taste would be due to altered TA responses rather than SSC/TA responses.

Weight Loss

We observed a constant increase in weight loss rate in all samples, namely, the control and samples treated with the ethylene absorbent, 1 $\mu L{\cdot}L^{-1}$ 1-MCP and 2 $\mu L{\cdot}L^{-1}$ 1-MCP, throughout the storage period. However, the differences in the rates of weight loss among samples were not statistically significant (Fig. 2). Therefore, 1-MCP and ethylene absorbent did not affect the rate of weight loss in the samples, which is in agreement with the results of Wills and Ku (2002), who reported that 1-MCP treatment did not affect the rate of weight loss in tomatoes during storage.

Color Change

Among Hunter L, a and b values, Hunter a (redness) values are best for evaluating the maturation process of tomatoes based on color. On day 6 of storage, samples treated with 1-MCP (2 $\mu L{\cdot}L^{-1}$) had significantly lower values of redness

Table 1. Effect of ethylene absorbent and 1-MCP on the titratable acidity (TA), soluble solids content (SSC) and pH of 'Dotaerang' tomato during storage

Parameter	Treatment	Storage (days)					
		0	3	6	9	12	15
TA (Acetic acid %)	C[z]	0.43 ± 0.01[y]	0.44 ± 0.02 a[x]	0.34 ± 0.00 b	0.36 ± 0.00 b	0.33 ± 0.01 c	0.33 ± 0.00 a
	E		0.44 ± 0.03 a	0.34 ± 0.01 c	0.36 ± 0.01 b	0.33 ± 0.01 c	0.30 ± 0.01 c
	1		0.37 ± 0.02 b	0.35 ± 0.00 b	0.34 ± 0.01 c	0.37 ± 0.00 b	0.30 ± 0.00 c
	2		0.46 ± 0.00 a	0.40 ± 0.00 a	0.44 ± 0.01 a	0.38 ± 0.00 a	0.31 ± 0.00 b
SSC (°Brix)	C	5.03 ± 0.15	5.17 ± 0.06 b	5.17 ± 0.06 bc	5.47 ± 0.12 b	5.40 ± 0.10 b	5.57 ± 0.15 a
	E		5.07 ± 0.06 b	5.13 ± 0.06 c	5.47 ± 0.06 b	5.60 ± 0.10 a	5.33 ± 0.06 b
	1		5.57 ± 0.12 a	5.27 ± 0.06 b	5.23 ± 0.06 c	5.63 ± 0.06 a	5.17 ± 0.12 b
	2		5.27 ± 0.15 b	5.67 ± 0.06 a	6.10 ± 0.10 a	5.43 ± 0.06 b	5.27 ± 0.12 b
pH	C	4.16 ± 0.05	4.21 ± 0.01 b	4.24 ± 0.01 a	4.18 ± 0.02 ab	4.23 ± 0.02 b	4.29 ± 0.01 a
	E		4.26 ± 0.01 a	4.23 ± 0.01 a	4.20 ± 0.03 a	4.26 ± 0.02 a	4.28 ± 0.02 a
	1		4.13 ± 0.01 c	4.24 ± 0.01 a	4.21 ± 0.02 a	4.15 ± 0.01 c	4.23 ± 0.02 b
	2		4.12 ± 0.01 c	4.19 ± 0.02 b	4.16 ± 0.01 b	4.08 ± 0.02 d	4.25 ± 0.03 b

Significance	TA	SSC	pH
Treatment (A)	***[w]	***	***
Days of storage (B)	***	***	***
A × B	***	***	***

[z]C, Control (No treatment); E, Ethylene absorbent; 1, 1 $\mu L \cdot L^{-1}$ 1-MCP; 2, 2 $\mu L \cdot L^{-1}$ 1-MCP.
[y]Data are means ± standard deviation.
[x]Values in the same column not sharing a common superscript are significantly different by Duncan's multiple range test ($p < 0.05$).
[wNS, *, **, ***]: Not significant or significant at $p < 0.05$, 0.01 or 0.001, respectively.

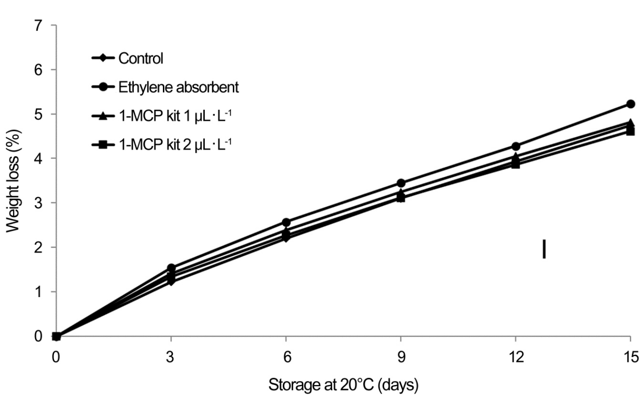

Fig. 2. Effect of ethylene absorbent and 1-MCP on the weight loss (%) of 'Dotaerang' tomato during storage. $LSD_{0.05}$ value for weight loss used for comparison of means is 0.41. The vertical bar represents the LSD value at $p = 0.05$ for comparison of means.

(Hunter a values) (2.24 ± 3.8) than the other treatments, including the control, and they exhibited delayed red coloration. The 1-MCP (1 $\mu L \cdot L^{-1}$) samples, ethylene absorbent and control samples had Hunter a values of 9.98 ± 3.37, 11.90 ± 2.88 and 13.39 ± 2.23, respectively on day 6. A similar tendency was observed in samples on day 9 of storage, with a Hunter a value for 1-MCP (2 $\mu L \cdot L^{-1}$) samples of 9.30 ± 4.82, which indicates a significant delay in the development of coloration. However, a negligible difference was detected among the 1 $\mu L \cdot L^{-1}$ 1-MCP, ethylene absorbent and control samples during storage. After day 12 of storage, full coloration was observed in all samples with no difference among samples, indicating that 1-MCP treatment delayed the development of red coloration during storage but the samples developed full coloration by the end of the storage period (Fig. 3). Indeed, 1-MCP treatment was previously found to delay the development of coloration in tomatoes for a certain period, followed by normal coloration (Mir et al., 2004; Mostofi et al., 2003). Choi and Bae (2007) found that treatment with increasing 1-MCP levels resulted in a more pronounced delay of coloration. In the current study, samples treated with 2 $\mu L \cdot L^{-1}$ 1-MCP showed more delayed coloration than samples treated with 1 $\mu L \cdot L^{-1}$ 1-MCP (Fig. 3).

The appearance of tomatoes during storage was in accordance with the Hunter L, a and b values measured with a colorimeter. After 3 days of storage, tomatoes from the control treatment exhibited more rapid coloration than tomatoes treated with ethylene absorbent, 1 $\mu L \cdot L^{-1}$ 1-MCP and 2 $\mu L \cdot L^{-1}$ 1-MCP. After 6 days of storage, these samples had red coloration, while the 1-MCP (2 $\mu L \cdot L^{-1}$)-treated samples showed the most delayed coloration. After 9 days, full coloration was observed in the control, as well as in samples

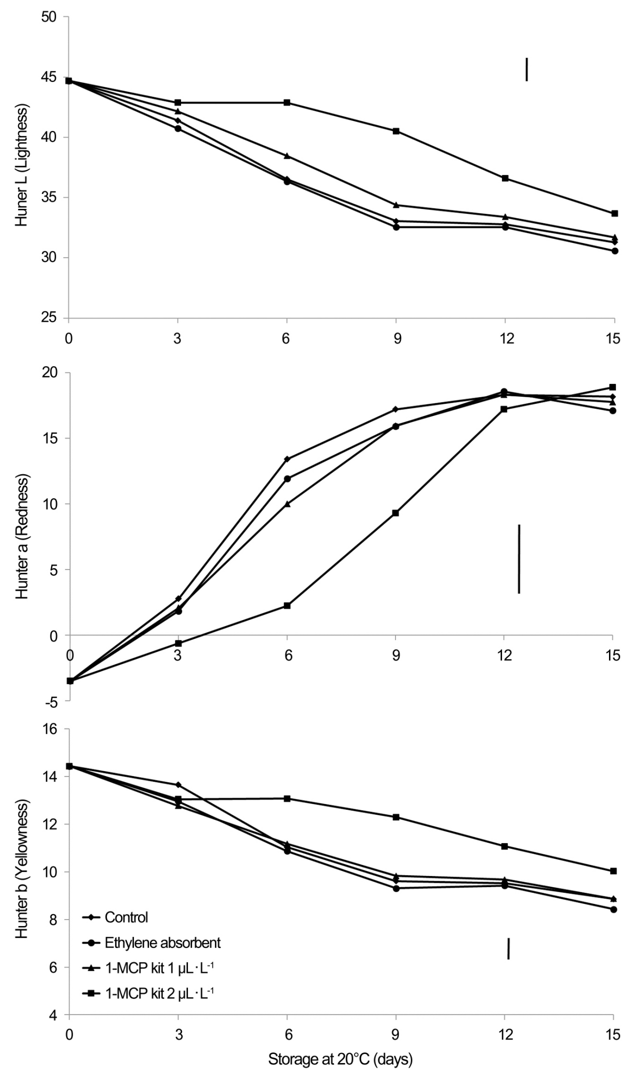

Fig. 3. Effect of ethylene absorbent and 1-MCP on the peel color of 'Dotaerang' tomato during storage. $LSD_{0.05}$ values for peel color used for comparison of means are 3.82 (L), 5.96 (a) and 1.36 (b), respectively. The vertical bar represents the LSD value at p = 0.05 for comparison of means.

treated with ethylene absorbent and 1 $\mu L \cdot L^{-1}$ 1-MCP, but not in samples treated with 2 $\mu L \cdot L^{-1}$ 1-MCP, leading to the conclusion that 2 $\mu L \cdot L^{-1}$ 1-MCP has the most efficient coloration delaying effect. After 15 days, all samples had complete red coloration (Fig. 4).

Changes in Firmness

During the first 3 days of storage, there were no significant changes in firmness. However, on day 9 of storage, samples treated with 2 $\mu L \cdot L^{-1}$ 1-MCP and 1 $\mu L \cdot L^{-1}$ 1-MCP showed higher firmness values (6.86 ± 0.31N and 6.67 ± 0.31N, respectively) than samples treated with ethylene absorbent (6.06 ± 0.62N) and control samples (6.04 ± 0.36N). This result can be explained by the delay of the softening process under 1-MCP treatment, which leads to greater firmness (Fig. 5). On day 15, the firmness did not significantly differ among samples. Therefore, 1-MCP treatment helped delay ripening, but the fruit eventually achieved the desired softness. This result is in agreement with previous reports showing that 1-MCP treatment can be used to maintain tomato firmness during storage (Mir et al., 2004; Mostofi et al., 2003; Opiyo and Ying, 2005).

Ethylene Production Rate

Ethylene production was not affected by the treatments. Ethylene production rates in the control and 1-MCP (1 $\mu L \cdot L^{-1}$) treatments were unchanged during storage. However, the ethylene production rate in the 1-MCP (2 $\mu L \cdot L^{-1}$) treatment was lower on day 6 than on day 15 (Table 2). Wills and Ku (2002) reported that 1-MCP treatment can affect the ethylene production rate in the first 5 days after treatment. After this period, 1-MCP treatment was reported to have no effect on ethylene production, which was confirmed by our results. Choi and Bae (2007) reported that treatment with low levels of 1-MCP does not inhibit ethylene production completely.

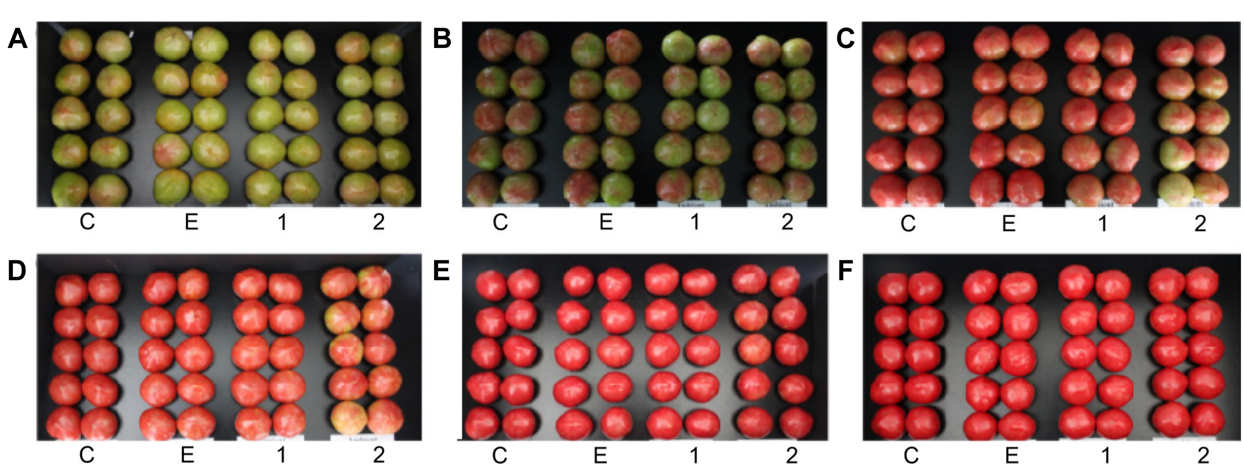

Fig. 4. Effect of ethylene absorbent and 1-MCP on the appearance of 'Dotaerang' tomato during storage. Harvest day (A), day 3 (B), day 6 (C), day 9 (D), day 12 (E), day 15 (F). C, Control (No treatment); E, Ethylene absorbent; 1, 1 $\mu L \cdot L^{-1}$ 1-MCP; 2, 2 $\mu L \cdot L^{-1}$ 1-MCP.

Table 2. Effect of ethylene absorbent and 1-MCP on ethylene production in 'Dotaerang' tomato during storage

Parameter	Treatment	Storage (days)					
		0	3	6	9	12	15
Ethylene production ($mL \cdot kg^{-1} \cdot h^{-1}$)	C[z]	0.3426 ± 0.013[y]	0.3241 ± 0.007 a[x]	0.3334 ± 0.008 a	0.3308 ± 0.006 a	0.3397 ± 0.004 a	0.3376 ± 0.005 a
	E		0.3300 ± 0.001 ab	0.3164 ± 0.004 b	0.3191 ± 0.005 b	0.3258 ± 0.006 ab	0.3403 ± 0.006 a
	1		0.3283 ± 0.007 a	0.3273 ± 0.008 a	0.3317 ± 0.008 a	0.3454 ± 0.008 a	0.3432 ± 0.009 a
	2		0.3208 ± 0.001 ab	0.2970 ± 0.030 b	0.3339 ± 0.005 ab	0.3319 ± 0.005 ab	0.3457 ± 0.003 a
Treatment (A)		NS[w]					
Days of storage (B)		**					
A × B		NS					

[z]C, Control (No treatment); E, Ethylene absorbent; 1, 1 $\mu L \cdot L^{-1}$ 1-MCP; 2, 2 $\mu L \cdot L^{-1}$ 1-MCP.
[y]Data are means ± standard deviation.
[x]Values in the same row not sharing a common superscript are significantly different by Duncan's multiple range test ($p < 0.05$).
[wNS, *, **, ***]: Not significant or significant at $p < 0.05$, 0.01 or 0.001, respectively.

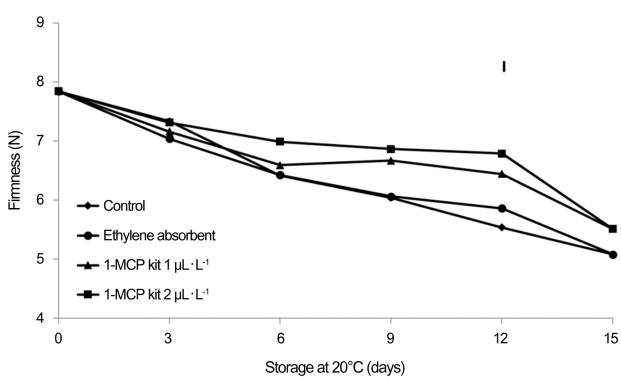

Fig. 5. Effect of ethylene absorbent and 1-MCP on the firmness of 'Dotaerang' tomato during storage. $LSD_{0.05}$ value used for firmness for comparison of means is 0.20. The vertical bar represents the LSD value at $p = 0.05$ for comparison of means.

Our results show that although ethylene production was not significantly different among treatments, treatment with 2 $\mu L \cdot L^{-1}$ 1-MCP inhibited red color development and maintained fruit freshness (Fig. 4).

Total Phenolic and Flavonoid Contents

We investigated the effects of the ethylene absorbent and 1-MCP treatment on the contents of antioxidant compounds in tomato compared to the control. There were no significant differences in total phenolic and flavonoid contents among treatments on day 15 of storage (Table 3), indicating that 1-MCP and the ethylene absorbent used in this study have no effect on the antioxidant contents of tomatoes at the end of storage. However, the total phenolic and flavonoid contents

Table 3. Effect of ethylene absorbent and 1-MCP on total phenolics and total flavonoid contents in 'Dotaerang' tomato during storage

Parameter	Treatment	Storage (days)					
		0	3	6	9	12	15
Total phenolics ($mg\ GAE \cdot kg^{-1}$ FW)	C[z]	185.70 ± 3.79[y]	219.03 ± 11.17 a[x]	202.13 ± 18.04 a	228.13 ± 10.53 b	248.23 ± 11.98 ab	236.76 ± 2.57 a
	E		186.05 ± 55.85 a	207.92 ± 16.48 a	231.09 ± 8.69 b	262.41 ± 21.36 a	242.55 ± 21.18 a
	1		226.00 ± 16.96 a	204.73 ± 19.84 a	289.36 ± 25.80 a	231.68 ± 1.25 b	242.55 ± 33.71 a
	2		210.64 ± 9.80 a	217.49 ± 12.17 a	228.84 ± 8.10 b	229.91 ± 10.26 b	229.20 ± 8.72 a
Total flavonoids ($mg\ CE \cdot kg^{-1}$ FW)	C	43.73 ± 4.36	47.65 ± 4.84 ab	48.04 ± 7.73 ab	58.10 ± 2.52 a	66.31 ± 4.01 a	54.67 ± 2.78 a
	E		51.24 ± 3.60 a	50.56 ± 1.47 a	48.63 ± 4.33 b	64.41 ± 2.61 a	47.58 ± 2.42 a
	1		37.71 ± 5.90 b	39.87 ± 3.17 b	63.46 ± 3.14 a	50.92 ± 3.01 b	47.58 ± 11.84 a
	2		39.15 ± 5.93 b	43.53 ± 3.76 b	51.41 ± 2.70 b	42.42 ± 2.69 c	54.25 ± 4.32 a

Significance	Total phenolics	Total flavonoids
Treatment (A)	**[w]	*
Days of storage (B)	***	***
A × B	***	***

[z]C, Control (No treatment); E, Ethylene absorbent; 1, 1 $\mu L \cdot L^{-1}$ 1-MCP; 2, 2 $\mu L \cdot L^{-1}$ 1-MCP.
[y]Data are means ± standard deviation.
[x]Values in the same column not sharing a common superscript are significantly different by Duncan's multiple range test ($p < 0.05$).
[wNS, *, **, ***]: Not significant or significant at $p < 0.05$, 0.01 or 0.001, respectively.

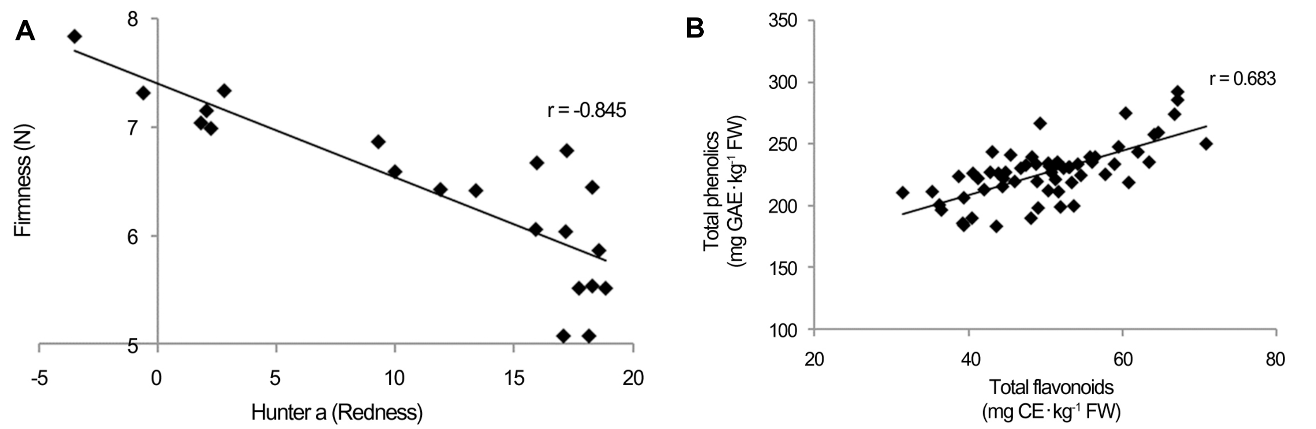

Fig. 6. Correlation coefficient (r) between firmness and Hunter a value (A) and between total phenolics and flavonoid contents (B) in 'Dotaerang' tomato.

increased during storage ($p < 0.001$).

A comparison of total phenolic content and degree of maturation revealed that the total phenolic content was 185.7 ± 3.79 mg GAE·kg^{-1} for tomatoes with a low degree of maturation (at harvest), whereas that of tomatoes with a high degree of maturation (day 15 of storage) was 237.77 ± 6.33 mg GAE·kg^{-1}. The total flavonoid content was 43.73 ± 4.36 mg CE·kg^{-1} at harvest and 51.02 ± 3.98 CE·kg^{-1} on day 15 of storage (Table 3).

Correlation of Physicochemical Characteristics

Although several studies have focused on analyzing the correlation between the physicochemical characteristics of fruits and their antioxidant compounds (Rekika et al., 2005; Shin et al., 2008; Shin 2012), most studies have focused only on examining the correlation among antioxidant compounds. In this study, we investigated the correlation between the two most important indexes of tomato maturation, namely, firmness and Hunter a value. We also investigated the correlation between the contents of total phenolics and total flavonoids. A high negative correlation coefficient (r = -0.845) was observed between the firmness and Hunter a values of tomatoes during storage ($p < 0.05$) (Fig. 6A). This result helps confirm the finding that during the maturation process, red coloration and lower firmness are strongly correlated. Additionally, a relatively high positive correlation coefficient (r = 0.683) was observed between the contents of total phenolics and total flavonoids ($p < 0.05$). These results help confirm the previous finding that higher levels of total phenolic compounds are strongly related to high levels of total flavonoids (Shin et al., 2008; Shin 2012) (Fig. 6B).

In conclusion, treatment with the small 1-MCP kit greatly inhibited tomato ripening in terms of appearance, color and firmness, with greater inhibition observed for 2 μL·L^{-1} treatment than 1 μL·L^{-1} treatment. This treatment did not affect total phenolic or total flavonoid contents compared to ethylene absorbent treatment and the control. These results indicate that the newly invented 1-MCP kit can be used to delay tomato ripening during distribution or storage. However, more studies are needed to determine the effects of various concentrations of 1-MCP and different treatment times.

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