Effects of 1-MCP on Quality and Storability of Cherry Tomato (Solanum lycopersicum L.)

Adanech Melaku Taye 1, Shimeles Tilahun 1,2,3, Mu Hong Seo 3, Do Su Park 4 and Cheon Soon Jeong 3,

1 Department of Horticulture and Plant Sciences, Jimma University, Jimma 378, Ethiopia; adanebaby@gmail.com (A.M.T); eyushim@gmail.com (S.T.)
2 Agriculture and Life Science Research Institute, Kangwon National University, Chuncheon 24341, Korea
3 Department of Horticulture, Kangwon National University, Chuncheon, Gangwon 24341, Korea; seomuhong@naver.com
4 Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV 26505, USA; dosu.park@mail.wvu.edu
* Correspondence: jeongcs@kangwon.ac.kr

Received: 6 March 2019; Accepted: 3 April 2019; Published: 12 April 2019

Abstract: Cherry tomato is a perishable fruit due to its high rate of ethylene production and respiration during ripening. 1-Methylcyclopropene (1-MCP) is known to control ripening and reduce decay of fruit by inhibiting ethylene action. In the present study, the influence of 1-MCP application on quality and storability of ‘Unicorn’ cherry tomato was observed. Fruit at pink and red maturity stages were put in the commercial plastic containers and sealed with 40 µm low density polyethylene (LDPE) film, treated with 1-MCP (0 µL L⁻¹ (control), 0.035 µL L⁻¹ and 0.1 µL L⁻¹), and stored at 10 °C in 85 ± 5% relative humidity (RH). The results indicated that application of 1-MCP at 0.1 µL L⁻¹ significantly affected firmness, cell wall thickness, water soluble pectin, weight loss, surface color, lycopene content and physiological parameters in both pink and red maturity stages compared to 0.035 µL L⁻¹ and control. 1-MCP treatment at 0.1 µL L⁻¹ kept the fruits firmer than 0.035 µL L⁻¹ and the control throughout the storage period for both maturity stages. Cell wall degradation in the control treatment was higher compared to the 0.1 µL L⁻¹ 1-MCP treated fruits in both maturity stages throughout the storage period. Results of this study revealed the effectiveness of application of 0.1 µL L⁻¹ 1-MCP on quality and shelf life of cherry tomato.

Keywords: cell wall thickness; lycopene; maturity stage; pectin; surface color; texture

1. Introduction

Tomato (Solanum lycopersicum L.) is a climacteric fruit and its ripening process is accelerated by ethylene and this endogenous production of that hormone results in short postharvest life [1,2]. Due to low storability of tomato fruits, various applications for extending fruit storability have been investigated, including 1-methylcyclopropene (1-MCP) technology. Several studies [3–5] reported that 1-MCP treatment prevents ripening effects or senescence of fruits and vegetables, thereby extending their shelf life. 1-MCP is known to block ethylene receptors and thus prevent ethylene effects on harvested fruit and vegetable plant tissues. 1-MCP is vaporous compound known to have a direct effect on ethylene binding sites and is being utilized to extend the shelf life of produce by controlling over-maturing and aging-related changes [5–7]. Furthermore, the effect depends on 1-MCP concentration and duration of treatment [5,6,8].

Tomatoes are commonly harvested at a green mature stage, before quality change has begun. Respiration plays a key role in keeping quality and shelf life of fresh produce. Klee et al. [9] stated...
the existence of the close association of ethylene production with fruit ripening in many species. Postharvest treatment with 1-MCP significantly affected ripening change of tomato fruit by hindering the production of ethylene [10]. Other ripening changes that are inhibited include respiration rates [4,11,12], development of color, and firmness degradation [10,11,13–16]. Moretti et al. [17] reported that treatments with higher concentrations (1000 mL L⁻¹) of 1-MCP delayed phytochemical changes and total carotenoid synthesis. According to [17], postharvest application of 1-MCP is an effective method to extend tomato fruit marketability, and when the concentration of 1-MCP treatment increased, fruit ripening was further delayed.

Cherry tomato fruit are known to have low storability; cognizant of this, many studies [18,19] have indicated various approaches for prolonging the storage period, including controlled atmosphere storage and heat treatment. Numerous studies [10,17,20,21] indicated effects of short term application of 1-MCP on different tomato varieties. To our knowledge, 1-MCP treatments of fruit sealed in a plastic container as a pre-storage treatment on different maturity stages of cherry tomato has not yet been reported. Therefore, this study was carried out to elucidate the effect of pre-storage 1-MCP treatments of packed fruit during storage at 10 °C in 85 ± 5% RH. In order to define the best 1-MCP treatment and maturity stage, we studied weight loss, changes in firmness, cell wall thickness, pectin content, lycopene content, color changes, and physiological characteristics of ‘Unicorn’ cherry tomato fruit.

2. Materials and Methods

2.1. Plant Material and Treatments

The common locally-grown cherry tomato (Solanum lycopersicum L.) cultivar, ‘Unicorn’, was grown on coir pith media in a climate-controlled glass house in Gangwon province, Republic of Korea, using a standard nutrient solution and standard cultivation practices. Fruit of uniform size and free from physical defects were harvested with an intact calyx at pink and red maturity stages. After harvest, fruit were directly transported within 30 min in an air-conditioned car to the postharvest laboratory of Kangwon National University. Immediately after arrival, the fruit were washed, wiped and air-dried for 4 h as described by [22], and a further careful selection of fruit was made in the laboratory using a color chart [23] to ensure uniform maturity of the sample fruit within each color group. Pink stage means the fruit surface was 30–60% pink or red and red stage means more than 90% of the fruit surface was red [23]. For each color group, 16 fruit were placed inside each 0.75 L plastic container and sealed with 40 µm LDPE film. The sealed containers were consequently categorized randomly for subsequent destructive and nondestructive analyses and treated with 1-MCP (Smart Fresh 1-MCP kit (FL Ecoplants, Seoul, Korea) at concentrations of 0.035 and 0.1 µL L⁻¹. The treated fruit were then stored at 10 °C with 85 ± 5% RH. Data was taken throughout the storage period from each treatment at two day intervals.

2.2. Flesh Firmness and Cell Wall Thickness

Flesh firmness was measured using a Rheo meter (Sun Scientific Co. Ltd., Tokyo, Japan) with a maximum force of 10 kg and a 3 mm diameter round stainless steel probe with a flat end. The results were expressed in Newtons (N).

Cell wall thickness was measured using scanning electron microscopy (SEM, Carlzeiss, Supra-55vp, Oberkochen, Germany). Sliced and frozen tomato samples were fixed in 4% glutaraldehyde solution and in 0.1 M Na-cacodylate buffer (pH 7.4) for 3–4 h, and then the 4% glutaraldehyde solution was pipetted off and cleaned in 0.1 M Na-cacodylate buffer (pH 7.4) 3 times for 10 min each time. After that, samples were dipped into and transferred from 50% ethanol → 60% ethanol → 70% ethanol → 80% ethanol → 90% ethanol → 100% ethanol. Finally, samples were dipped sequentially into solutions of 100% ethanol: 100% isoamyl acetate: 2:1; 100% ethanol:100% isoamylacetate: 1:1; 100% ethanol:100% isoamyl acetate: 1:2; and 100% isoamyl acetate, for 20 min in each solution. Then, samples were dried with a critical point drier (HCP-2, Hitachi, Tokyo, Japan), ion sputter coated with gold, and examined by VP-FE-SEM (Supra 55VP, Carl Zeiss, Germany) at an accelerating voltage of 3 kV. Digital image
analyses were subjected to free NIH Image software (http://rsb.info.nih.gov/nih-image/) to measure the outer, middle, and inner cell wall thicknesses, with a little modification of [24].

2.3. Extraction of Ethanol Insoluble Solid (EIS) and Pectin Analysis

Ethanol (80%) was added to 5 g frozen cherry tomato samples and homogenized [25]. The mixture was boiled at 100 °C in a water bath for 10 min, cooled to room temperature, and filtered through Mira cloth (Calbiochem, La Jolla, CA, USA). The residue was washed with 10 mL 80% ethanol and 10 mL 100% acetone, dried in a desiccator at 38 °C, and stored at room temperature for 10 min with little modification [25]. Afterwards, 10 mg of EIS was placed in a test tube and put on ice, to which was added 2 mL 98 % H₂SO₄. Test tubes were incubated at room temperature for 12–18 h. The incubated samples were diluted with 15 mL of distilled water, and the dilution with distilled water continued with shaking until the volume reached 25 mL. After complete dissolution, a 0.4 mL sample was taken from the diluted sample and added to 40 µL of 4 M sulfamate-KOH and 2.4 mL of 98 % H₂SO₄ containing 75 mM sodium tetraborate. The sample mixture was boiled for 20 min at 100 °C and cooled to the room temperature for 10 min. After cooling, 80 µL of 0.15% m-phenylphenol was added and mixed well. Absorbance readings were taken after 20 min by using a spectrophotometer (Thermo Fisher Scientific, Madison, WI, USA) at 520 nm. The concentration was calculated from a standard curve of galacturonic acid as described by [26].

2.4. Weight Loss, Peel Color, and Lycopene Content

Fruit were initially weighed before applying the treatments, and loss in weight was measured at each day of observation. The loss of weight was calculated by subtracting the weight of the fruit each day from the initial weight [27].

Cherry tomato peel color readings were taken around the equatorial axes of the fruit using a CR-400 Chroma Meter (Minolta, Tokyo, Japan). The resulting Hunter L*, a*, and b* values represent the degree of lightness or darkness, green to red, and blue to yellow, respectively.

Lycopene content was measured using a spectrophotometer (Thermo Fisher Scientific, Madison, WI, USA). One gram of frozen sample was homogenized in 1 mL distilled water. The homogenate was further diluted with 2:1:1 of 20 mL of n-hexane, acetone, and ethanol, respectively. The mixture was centrifuged in 15,000 rpm for 20 min. Afterwards, 3 mL of distilled water was added to each sample which were agitated for 2 min and left at room temperature for a few minutes until phase separation was achieved. Each sample was then read using the spectrophotometer at 503 nm and the lycopene content was calculated according to [28].

2.5. Ethylene, Acetaldehyde, Ethanol, and Respiration Rate Measurements

The sealed cherry tomato fruit were removed from their package allowing air circulation for 1 h. Sample fruit were then placed in an airtight 1 L container. After a 3 h incubation as described by [22], a 1 mL gas sample was then collected from each container using a gas tight syringe and injected into a GC-2010 Shimadzu gas chromatograph (Shimadzu Corporation, Tokyo, Japan). Ethylene, acetaldehyde and ethanol concentration were measured using a BP 20 wax column (30 m × 0.25 mm × 0.25 µm, SGE Analytical Science, Melbourne, Australia) and a flame ionization detector (FID). The detector and injector operated at 127 °C and oven were 50 °C and carrier gas (N) flow rate was 0.67 mL s⁻¹ [29]. All of them were expressed as (µL kg⁻¹ h⁻¹). CO₂ concentrations in the container headspace was analyzed before and after a 3 h incubation using a gas analyzer (CheckMate 9900; PBI-Dansensor, Ringsted, Denmark); the result was expressed as mg CO₂ kg⁻¹ h⁻¹.

2.6. Statistical Analysis

The experiment was conducted in a completely randomized design with five replications per treatment for firmness and water-soluble pectin, three replications per treatment for cell wall thickness, weight loss, ethylene, respiration rate, lycopene, acetaldehyde, and ethanol, and nine replications per
3. Results

3.1. Firmness

Firmness of cherry tomato was significantly influenced by pre-storage 1-MCP application and stage of maturity. The high concentration (0.1 µL L\(^{-1}\)) of 1-MCP maintained fruit firmness of both maturity stages throughout the storage period at 10 °C and 85 ± 5 RH, as compared to the 0.035 µL L\(^{-1}\) 1-MCP and control groups (Figure 1). No significant difference was observed among the control and 0.035 µL L\(^{-1}\) 1-MCP treated fruit. At the beginning of storage, firmness was 10.57 N and 9.80 N in pink and red stages, respectively. On the 15th day, firmness was reduced to 7.75 N and 6.08 N in pink and red stages, respectively for 0.1 µL L\(^{-1}\) 1-MCP-treated fruit. Nevertheless, 0.035 µL L\(^{-1}\) 1-MCP-treated fruit and control in both stages did not maintain firmness. The firmness of 0.1 µL L\(^{-1}\) 1-MCP-treated fruit slightly increased until the 11th day in pink and until the 9th day in red stages and decreased gradually afterwards. 1-MCP at 0.035 µL L\(^{-1}\) and control fruit were similar in firmness until the 7th day and then control fruit firmness decreased sharply, while 0.035 µL L\(^{-1}\) 1-MCP-treated fruit stayed firmer than controls until the end of the storage period with a gradual decrease over time.

Figure 1. Effect of 1-MCP application at the pink and red maturity stages on flesh firmness and water-soluble pectin of cherry tomato (‘Unicorn’) stored at 10 °C for up to 15 days. Each datum point is the mean of five fruit replicates ±SE (n = 5); some SE bars are not larger than the symbols. Means within days of storage with the same letters are not significantly different at P ≤ 0.05.
3.2. Water-Soluble Pectin

The ANOVA results showed significant differences among the treatments on both maturity stages (Figure 1). Water soluble pectin content increased as the storage period proceeded with significant difference between treatments. 1-MCP application at 0.1 µL L\(^{-1}\) showed a reduction of water-soluble pectin. This showed that 1-MCP can inhibit degradation and solubilization of pectic polysaccharides during storage. However, 0.035 µL L\(^{-1}\) and control treatments showed an increase in water soluble pectin as the storage period proceeded.

3.3. Cell Wall Thickness

The outer cell wall layer was significantly affected by the stage of maturity and 1-MCP application (Figure 2A). In the pink maturity stage, high cell wall thickness values were recorded at 7 and 15 days (27.58 and 25.45 µm, respectively) (Figures 2A and 3). The outer cell wall degradation of the control was higher compared to the 0.1 µL L\(^{-1}\) 1-MCP-treated fruit from both maturity stages over time (Figure 2A,D and Figure 3). The outer cell wall thickness was higher in the pink maturity stage than the red stage, and it showed a slight increase during storage when treated with 1-MCP in the red maturity stage. Changes on middle cell wall thickness showed similar trends with the outer cell wall thickness as mentioned above on both maturity stages (Figure 3). Inner cell wall thickness was significantly influenced by 1-MCP treatment and maturity stages (Figure 3). A difference of the inner cell wall thickness was observed on the 15th day in the pink maturity stage, whereas there was no significant difference on harvest day and the 7th day. Similarly, there was a significant difference between control group and 0.1 µL L\(^{-1}\) 1-MCP on changes of inner cell wall thickness on the 7th day, but the inner cell wall thickness showed a slight reduction on the 15th day compared to the 7th day.

![Figure 2](image_url)  
**Figure 2.** Effect of 1-MCP application on outer (A,D), middle (B,E) and inner (C,F) cortex of cell wall thickness when applied in pink (A–C) and red (D–F) maturity stages of cherry tomato (’Unicorn’) stored at 10 °C for up to 15 days. Each datum point is the mean of three fruit replicates ±SE (n = 3); some SE bars are not larger than the symbols. Means with the same letters are not significantly different at P ≤ 0.05.
Figure 3. Effect of 1-MCP application applied in the pink and red maturity stages on cell wall thickness of cherry tomato. SEM analysis (EHT = 3.00 kV, Mag = 1.00 K X, scale bar = 20 µm).

3.4. Peel Color

The changes in color L*, a* and b* values are presented in Figure 4. In the pink maturity stage, the Hunter L* value was higher than the red stage in the first 3 days and showed a decreasing trend afterwards in all treatments. This indicates that, with a prolonged storage period, fruit brightness decreased, because with ripening of the fruit, red color development advanced [27]. Also, for the red maturity stage, there was no significant difference between treatments. Hunter a* values of the pink stage cherry tomato were affected by 1-MCP application during storage. Hunter a* values of the pink stage reached its peak on the 7th day of storage, whereas 0.1 µL L⁻¹ 1-MCP-treated fruit reached a peak on the 11th day (Figure 4). Similarly, for the red maturity stage, the 0.1 µL L⁻¹ 1-MCP treatment maintained more fruit color than the control and the 0.035 µL L⁻¹ 1-MCP treatment (Figure 4). There was no significant difference between treated and untreated fruit until day 5 for red maturity stage fruit, whereas after day 7 there was slight decline in redness throughout storage period for both the control and 0.035 µL L⁻¹ 1-MCP. However, 0.1 µL L⁻¹ 1-MCP maintained the redness of the fruit until the end of the storage period. In both maturity stages, Hunter b* (yellowness) values were higher during the first 7 days. Afterwards, there was reduction of b* value as the storage period proceeded (Figure 4).
3.5. Weight Loss (%)

Pre-storage 0.1 µL L⁻¹ 1-MCP application had a significant influence on weight loss of both maturity stages (Figure 5) compared to control and 0.035 µL L⁻¹ 1-MCP-treated fruit. On the 3rd day weight loss was about 0.013% for control, 0.411% for 0.035 µL L⁻¹ and 0.011% for 0.1 µL L⁻¹ 1-MCP treatment, and it increased to 2.66%, 3.27% and 1.26% in control, 0.035 µL L⁻¹ and 0.1 µL L⁻¹ of 1-MCP treatments, respectively, by the 15th day for fruit treated in the pink stage. For fruit treated in the red stage, weight loss in controls was very high compared to 1-MCP-treated fruit until the 11th day of storage (Figure 5).
However, in both the control and 0.035 µL L\(^{-1}\) 1-MCP treatments, a peak was observed at the 3rd day after treatment. Ethylene production rate in the pink stage fruit increased until the 3rd day for the 0.035 µL L\(^{-1}\) 1-MCP treatment and until the 5th day in control, and then kept decreasing until the end of the storage period (Figure 5). After the 11th day of storage, all treatments showed a declining trend in ethylene production rate. The respiration rate stayed lower in 1-MCP treated fruits compared to controls in both maturity stages (Figure 5).

Formation of acetaldehyde and ethanol were affected by 0.1 µL L\(^{-1}\) 1-MCP application in both maturity stages (Figure 6). After 3 days of treatment at the pink maturity stage, acetaldehyde production showed an increasing trend throughout the storage period in 0.035 µL L\(^{-1}\) 1-MCP and control groups.
In case of fruit treated at the red maturity stage, there was a high production of acetaldehyde in 0.035 µL L⁻¹ 1-MCP and the control fruits at the beginning and both showed an increasing trend throughout the storage period. Whereas a low level of acetaldehyde production was observed in 0.1 µL L⁻¹ 1-MCP fruit during the entire storage period (Figure 6). The ethanol production rate showed an increasing trend in fruits treated with 0.035 µL L⁻¹ 1-MCP and the controls during the entire storage period for both maturity stages (Figure 6).

3.7. Lycopene Content

Significant differences in lycopene content were observed among treatments except at the beginning day in fruit treated in the pink stage (Figure 6). Lycopene content at the beginning was the same for all treatments, and it reached its peak on the 7th and 11th days in the control and 0.035 µL L⁻¹ 1-MCP treatments, respectively. Similarly, in 0.1 µL L⁻¹ 1-MCP-treated fruit, lycopene content showed...
an increasing trend throughout the storage period for pink stage fruit (Figure 6). In red stage fruit, all treatments maintained lycopene content until the 11th day of storage. After the 11th day, the lycopene content significantly decreased in the control and 0.035 µL L⁻¹ 1-MCP treatments. However, 0.1 µL L⁻¹ 1-MCP maintained the lycopene content until the end of the experiment in red maturity stage fruit (Figure 6).

4. Discussion

The results showed that control fruits in the red maturity stage showed the lowest firmness value (5.5 N) on the 15th day of storage at 10 °C. A sharp reduction in firmness of non-treated fruit could be associated with ethylene production and respiration. In line with our findings, Miranda et al. [30] reported a slow and continuous decrease of fruit firmness of control fruit correlated with climacteric ethylene production. Moretti et al. [17] also reported shriveling and softening of fruit at both maturity stages and degradation of cell walls correlated with an increase of ethylene production and respiration rate, which led to softening of fruits. Similarly, Jeong et al. [31] reported an increased softening rate of tomato at a higher rate of ethylene production. In this study, fruit treated with 0.1 µL L⁻¹ 1-MCP were firmer than 0.035 µL L⁻¹ 1-MCP-treated fruit and controls during the entire storage period. This could be due to the inhibition of a degradation of cell walls and reduced hydrolysis of water-soluble pectin. Moreover, 0.1 µL L⁻¹ 1-MCP-treated fruits maintained compactness of cell walls for both maturity stages. Likewise, Krammes et al. [12] and Miranda et al. [32] reported an inhibitory effect of 1-MCP on respiration rate during storage, which in turn has resulted in reduction of hydrolysis of pectin and enzymatic activities such as polygalacturonase over the storage period. Patricia et al. [33] observed increased hydrolysis of soluble pectin in sapodilla cell walls as fruit ripening proceed. Pinheiro et al. [34] also found similar 1-MCP effects on soluble and total pectin contents as tomato and bananas ripened. Similarly, delayed softening of peach during storage was directly associated with delayed increase of water-soluble pectin content [35].

1-MCP treatment in the present study revealed its effectiveness in reducing respiration rate and weight loss. Our result agrees with Guillen et al. [36] who reported lower weight loss in tomato fruit treated with 1-MCP as compared to controls. 1-MCP treatment also reduced color development in cherry tomato thereby slowing down ripening and in turn extending its shelf life. Similarly, Moretti et al. [17] reported initiation of fruit color development within 5 days in pink control fruit as compared to 1-MCP-treated fruit which needed a minimum of 7 days for color changes. Porat et al. [37] also reported that 1-MCP treatment inhibited the de-greening of citrus fruits. Therefore, treating cherry tomato with 1-MCP can extend shelf life without affecting color quality. The color of tomato fruit is the result of synthesis of carotenoids as chloroplasts transform to chromoplasts [38,39]. Lycopene is the most abundant carotenoid, comprising approximately 90 percent of the carotenoids present in tomato, responsible for the development of deep red color of ripe tomato fruit [40]. In this study, lycopene content reached its peak earlier in the control than in 1-MCP-treated fruit, indicating that 1-MCP treatment delays color development in tomato and thereby it delays lycopene accumulation (Figure 6). Moreover, the treatment of fruit with 0.1 µL L⁻¹ 1-MCP delayed lycopene accumulation as compared to 0.035 µL L⁻¹ 1-MCP treated and control fruit. This result agrees with Moretti et al. [17] who reported slower carotenoid synthesis in 1-MCP-treated tomato fruit and a significant effect with higher concentrations.

1-MCP application reduced the ethylene production rate; hence it is useful to increase the shelf life of the cherry tomato fruits. Mostofi et al. [15] reported that 1-MCP prevented buildup of mRNA responsible for expression of ACC synthase, ACC oxides, and ethylene receptors in tomato. The rate of respiration decreased over time during storage period for all treatments. The respiration rate stayed lower in 1-MCP-treated fruits compared to controls for both maturity stages of cherry tomato (Figure 5). Various authors [4,11,12] also reported inhibitory effects of 1-MCP on respiration rate during storage. In this study, the production of acetaldehyde and ethanol were almost not detectable in 0.1 µL L⁻¹ 1-MCP-treated fruit for both maturity stages. This result is supported by the finding of Mir et al. [14]
who reported minor shifts in aroma of 1-MCP-treated tomato fruit. The overall sensory evaluation by five trained panelists (data not shown) at the end of the storage period also showed the acceptability of fruit treated with 1-MCP.

5. Conclusions

Cherry tomato fruit treated with 0.1 µL L\(^{-1}\) 1-MCP had better quality and storability compared to 0.035 µL L\(^{-1}\) 1-MCP-treated and control fruit. Therefore, pre-storage treatment of cherry tomato fruit with 1-MCP at 0.1 µL L\(^{-1}\) after sealing in commercial plastic containers with 40 µm LDPE film followed by storage at 10 °C in 85 ± 5% can maintain freshness of cherry tomato fruit up to 15 days. In addition, pre-storage 1-MCP treatment of the sealed fruit could ease handling and distribution as it does not need further packaging to reach the ultimate consumers.


Funding: This research was funded by rural development administration, Republic of Korea, with the support of 2018 research projects (PJ013876012018).

Conflicts of Interest: The authors declare no conflict of interest.

References


