Selection of Non-Perforated Breathable Film to Enhance Storability of Cherry Tomato for Modified Atmosphere Storage at Different Temperatures

Mohammad Zahirul Islam¹, Mahmuda Akter Mele¹, Han Jong Lee¹, Kyoung Soo Lee¹, Sung Mi Hong¹, Min Jae Jeong¹, Il-Seop Kim¹, Soon-Kwan Hong², In-Lee Choi¹,², Jun Pill Baek¹,³, and Ho-Min Kang¹,³*

¹Department of Horticulture, Kangwon National University, Chuncheon 200-701, Korea
²Department of Bio-Health Technology, Kangwon National University, Chuncheon 200-701, Korea
³Agriculture and Life Science Research Institute, Kangwon National University, Chuncheon 200-701, Korea

Abstract. This study was conducted to find out the appropriate packaging materials to extend the storability and maintain the quality of cherry tomato for modified atmosphere (MA) storage. Tomatoes were grown by hydroponic at a plastic house in Gangwon Province. Light red maturity stage tomatoes were harvested and packed with MA condition (10,000; 20,000; 40,000; 60,000; 80,000; and 100,000cc/m².day.atm O₂ permeability film) and perforated film to store at 5°C, 11°C and 24°C. The fresh weight loss was less than 0.6% in all non-perforated breathable films at 5°C, 11°C, and 24°C, but perforated film had less than 2.93% at 5°C, 13.29% at 11°C and 27.24% at 24°C. The 20,000cc at 5°C and 11°C, and the 40,000cc film at 24°C balanced optimum carbon dioxide and oxygen concentration in the package to maintain quality. The 10,000cc film was appeared the significantly highest ethylene concentration at 5°C, 11°C, and 24°C, this film had the lowest O₂ permeability. Visual quality, firmness, and soluble solids were maintained in 20,000cc films both at 5°C and 11°C, the 40,000cc film at 24°C. There was no any trend in titratable acidity and vitamin C content of treated packed film types and temperatures at cherry tomatoes packages. Therefore, the appropriate MA condition for 5°C and 11°C is 20,000cc/m².day.atm O₂ permeability film; for 24°C it is 40,000cc/m².day.atm O₂ permeability film because those films extended the storability through the firmness, soluble solids as well as visual quality.

Additional key words: Firmness, soluble solids, vitamin C, and visual quality

Introduction

Modified atmosphere packaging (MAP) is a vigorous process of altering gaseous formation inner package (Caleb et al., 2013). The MAP is a post-harvest technology vastly used to extend and preserve the shelf-life of fresh, enhance the product of the image and lessen waste (Montanez et al., 2010). The MA packaging of refreshing produce depends on modification of the atmosphere inside the package, obtained by the natural reciprocation between two processes, the respiration of the product and to convey of gases by the packaging that leads to an atmosphere higher in carbon dioxide and lower in oxygen (Mahajan, et al., 2007). An inappropriately designed MA packaging system may be feeble towards extending the storage life of packaged produce, if the desired or optimal atmosphere is not formed rapidly innermost the package (Oliveira et al., 2012). Toxic effects may occur if the levels of oxygen and carbon dioxide are not within the range tolerated by the commodity (Iqbal et al., 2009a). Ignoble temperature together with low and high carbon dioxide levels, are widely adopted to degrade the respiration rate of fresh produce and broaden their shelf life (Iqbal et al., 2009b).

The carbon dioxide (3-4%) and oxygen concentration (16-18%) in ‘Madison’ tomato packages showed proper levels for MA storage in 20,000cc breathable film at 5°C storage (Islam et al., 2011). The optimal conditions to keep high quality of tomato fruits were obtained by MA packaging during storage at 0°C for 29 days, independently of the film thickness, in which the adequate gas composition was carbon dioxide at 4.2%-5.6%, oxygen at 14.3%-14.5%, respectively (Guan et al., 2008).

The MA packaging has some ineffective towards from an improper use and effective from a proper use. Perishable crop needed suitable MA packaging to retain post-harvest quality. We did this experiment because there was no study on O₂ permeability film for cherry tomato with different storage temperatures. This study was conveyed to find out the proper non-perforated breathable film for MAP to extend the storability of cherry tomato.
Materials and Methods

Tomato plants (Lycopersicon esculentum Mill. cv. 'Unicorn') were grown by hydroponics during summer at a plastic house in Gangwon province. Supplied nutrient solution was adjusted to EC 2 dS.m$^{-1}$ and pH 5.8–6.2 recommended by the Japanese horticultural experiment station (Sato et al., 2006). Tomato plants were maintained with standard practices for training, suckering, pruning lower leaves, cluster pruning (Hochmuth, 1991) along with auxiliary bud pruning. The plastic house was maintained at maximum 32°C by air circulation and shading system. Tomatoes were harvested at light red maturity stage packaged with 10,000; 20,000; 40,000; 60,000; 80,000; and 100,000cc/m$^2$.day.atm O$_2$ permeability film as well as perforated film (100,000cc/m$^2$.day.atm O$_2$ permeability film used as a perforated film by making 0.6cm diameter 4 hole in 12.5cm $\times$ 8.2cm $\times$ 3.5cm size package) to store at 5°C, 11°C and 24°C with 85% relative humidity.

The fresh weight loss of tomatoes during the storage period was measured by subtracting sample weights from their previous recorded weights, and presented as % of weight loss. Visible quality was subjectively assessed fruits based on visual quality determinants such as freshness, mould growth, decay, shriveling, smoothness, shininess and homogeneity. The scale of visual quality was observed on 1 to 5 (1 = waste; 2 = bad; 3 = good, marketable; 4 = very good; and 5 = excellent) during 5°C, 11°C, and 24°C storage. Five panel members were employed to assess the visual quality of the tomatoes.

The oxygen and carbon dioxide concentrations in packages were measured by PBI Dansensor (Check mate 9900, Denmark). The ethylene was measured by GC 2010 Shimadzu (Shimadzu corporation, Japan) equipped with BP 20 Wax column (30m $\times$ 0.25mm $\times$ 0.25µm, SGE analytical science, Australia) and a flame ionization detector (FID). The detector and injector operated at 127°C along with the ovens were at 50°C, as well as carrier gas (N$_2$) flow rate was 0.67mL/s (Park et al., 2000).

Firmness (N) was measured using a penetrometer (DFT-01, TR snc, Italy). Soluble solid was measured by refractometer (Atago U.S.A.Inc.,U.S.A.) and results were read directly in °Brix. Titratable acidity was measured by Food & Beverage Analyzer (DL22, Metter Toledo Ltd., and Korea); by using 0.1N NaOH solution and results were reported as % citric acid. Vitamin C measured by RQflex plus (Merck, Germany) with mg/100gFW (Arvanitoyannis et al., 2005).

Statistical Analysis. Graphs were produced using GraphPad prism 5 (GraphPad Software, Inc., USA). Fresh weight loss, visual quality, oxygen concentration, carbon dioxide concentration, ethylene concentration was analyzed by Dunnett’s Multiple Comparison Test of one-way ANOVA. Statistic analyses of firmness, soluble solids, titratable acid-
Results and Discussion

The highest and the lowest fresh weight loss shown by perforated film and 10,000cc/m².day.atm O₂ permeability film, respectively, during the storage period at 5°C, 11°C, and 24°C. The fresh weight loss lower at 5°C, followed by 11°C, and 24°C. So, higher temperature had a negative effect in fresh weight of tomato. Until the final storage day, our result did not exceed the maximum permissible of 7% fresh weight loss (Kays and Paull, 2004) in MAP which range was 0.16–0.22% at 5°C, 0.19–0.43% at 11°C, 0.30–0.53% at 24°C, but perforated film overlapped the maximum permissible fresh weight loss at 11°C and 24°C. It is directly related with Valverde et al., (2005) that loss of weight in MAP packaged was very low (< 1%), mainly due to the effect of polypropylene film on expanding by vapor. But the fresh weight loss of perforated film showed 13.29%, and 27.24%, at 11°C, and 24°C, respectively on the final storage day.

The 20,000cc which showed the highest visual quality maintained around 5–9% carbon dioxide and 13–16% oxygen at 5°C, and 5–12% carbon dioxide and 11–16% oxygen at 11°C. Moreover, the 40,000cc also maintained 9–11% carbon dioxide and 12–14% oxygen at 24°C (Fig. 3). The concentrations of carbon dioxide and oxygen inside the MA package (0.03 or 0.06mm) were about 4.21–8.17% and 9.78%–14.45% under steady state during storage 29 days at 0 and 5°C, respectively in mature-red tomato fruits (cv. Pinky World) (Gu, et al., 2008). The recommended controlled or modified atmosphere conditions during transport and/or storage of ripe tomato is 3–5% oxygen and 3–5%, carbon dioxide at 10–15°C (Kader, 2002). Moreover, MA packaging, carbon dioxide at 5 to 10%, added to oxygen level below 5%, is an effective fungistat that can be used for decay control on commodities that do not tolerate 15 to 20% carbon dioxide (Kader, 2002). Rodriguez-Aguilera and Oliveira, (2009) reported that reduced levels of oxygen and increased levels of carbon dioxide in the atmosphere surrounding fresh produce seem to have several positive effects: they preserve product quality because they slow down respiration, and decrease softening rates.

The 10,000cc film showed significantly (p< 0.05) the highest ethylene concentration that was stored at 5°C, 11°C, and 24°C (Fig. 3). Ethylene influenced internal quality such as firmness (Stow et al., 2000) and the threshold for ethylene action in tomato is 0.5ppm (Kader, 2002). However 20,000cc film at 5°C, 11°C and 40,000cc film at 24°C showed moderate ethylene concentration (around 2µL/L) maintained highest visual quality and firmness, because atmosphere conditions of those films were close to proper MA condition (Kader, 2002).

Firmness is an important aspect of fresh tomato quality, and it decreases over time (Islam et al., 2011). The
Selection of Non-Perforated Breathable Film to Enhance Storability of Cherry Tomato for Modified Atmosphere Storage

20,000cc film both 5°C and 11°C, and the 40,000cc film at 24°C had shown the highest firmness. The 20,000cc film showed the highest firmness in ‘Madison’ tomato at 5°C for 20 days and thereafter 20°C for 5 days storage condition (Islam et al., 2011). The 10,000cc film at 5°C and 11°C, and the perforated film at 24°C have shown the lowest firmness because of higher fresh weight loss, shriveling, softening and lower shelf life in all treatments. Moreover, the firmness of tomato packed with 10,000cc film at 5°C and 11°C should be affected by higher ethylene concentration in film. There was a significant difference at 5°C of the 20,000cc film and at 24°C of the 40,000cc film compared with perforated film (Table 1).

Both 5°C and 11°C, the 20,000cc film and at 24°C the 40,000cc film had shown the highest soluble solids because those film maintained optimum atmosphere in the MAP (Table 1). The mean soluble solids value of 5°C, 11°C and 24°C were 6.87, 6.53, and 6.12, respectively at the after storage day. The ripening and storage period progressed, soluble solids increased over a certain period, and decreased significantly ($P<0.05$) afterwards (Islam et al., 2012). Perforated film showed higher soluble solids in 5°C and 11°C due to concentration effect by fresh weight loss, because fresh weight loss was the highest in perforated film treatment at all temperatures. Choi et al., (2002) reported that the concentration effect of soluble solid that is caused by a large decrease of fresh weight in tangor MAP experiment.

The average titratable acidity was performed at 0.53 for 5°C, 0.33 for 11°C and 0.39 for 24°C after storage day (Table 1). At 5°C tomatoes indicated the highest titratable acidity because of delaying ripeness (data not shown). The higher acidity value of cherry tomatoes was recorded at
Islam et al. (2012) indicated that low temperature delayed ripening of tomato (Madison and Unicorn). Changes in acidity are also important in the development of the characteristics taste in many fruits, and the organic acid decreased in most fruits during ripening (Kays and Paull, 2004).

The highest vitamin C was performed by 10,000cc film at 5°C and 11°C and 20,000cc film at 24°C, and the lowest showed by 60,000cc film at 5°C, 11°C and 24°C (Table 1). The vitamin C content of all treated tomatoes decreased during the storage period. The average value of vitamin C was 8.12, 8.46, and 9.52mg/100g fresh weight at 5°C, 11°C and 24°C, respectively. Storage for 6 days in carbon dioxide-enriched atmospheres resulted in a reduction in ascorbic acid content of sweet pepper kept at 13°C (Wang, 1977).

Atmospheric modification reduces physiological and chemical changes of fruits and vegetables during storage, and loss of ascorbic acid can be reduced by storing apples in a reduced oxygen atmosphere, and high carbon dioxide concentration in the storage atmosphere caused degradation of vitamin C in fresh-cut kiwifruit slices (Lee and Kader, 2000).

The appropriate MAP condition for both 5°C and 11°C is 20,000cc film, and for 24°C is 40,000cc film because those films increase storability, maintain visual quality, soluble solids and retain firmness. Those films would be allowing adequate gas exchanges for tomatoes. Moreover, O₂ permeability films can provide fresher tomatoes, safe public health, help avoid chemicals during storage, and also help to earn foreign currency by satisfying the buyers as well as consumers.

Acknowledgement
This study was supported by Bio-industry Technology Development Program (No. 111080-03), Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea.

Table 1. The firmness, soluble solids, titratable acidity and vitamin C of ‘Unicorn’ tomato at 5°C, 11°C, and 24°C after storage (perforated film, 10,000; 20,000; 40,000; 60,000; 80,000; 100,000cc/m².day.atm O₂ permeability film).

<table>
<thead>
<tr>
<th>Storage temps.</th>
<th>Firmness (N)</th>
<th>Soluble solids (°Brix)</th>
<th>Titratable acidity (% citric acid)</th>
<th>Vitamin C contents (mg/100gFW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°C (25days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5°C (15days)</td>
<td>11.35b</td>
<td>10.76b</td>
<td>13.90bc</td>
<td>5.87bc</td>
</tr>
<tr>
<td>11°C (9days)</td>
<td>16.05a</td>
<td>18.07a</td>
<td>6.78ab</td>
<td>5.76bc</td>
</tr>
<tr>
<td>24°C (9days)</td>
<td>12.69c</td>
<td>18.55a</td>
<td>6.54abc</td>
<td>5.59bc</td>
</tr>
<tr>
<td>10,000cc</td>
<td>7.08abc</td>
<td>7.25a</td>
<td>7.20ab</td>
<td>4.92b</td>
</tr>
<tr>
<td>11.05a</td>
<td>6.85a</td>
<td>6.77ab</td>
<td>6.42bc</td>
<td>4.97ab</td>
</tr>
<tr>
<td>20,000cc</td>
<td>10.76b</td>
<td>10.09a</td>
<td>17.33ab</td>
<td>6.20bc</td>
</tr>
<tr>
<td>13.90bc</td>
<td>13.26a</td>
<td>16.09a</td>
<td>16.03bc</td>
<td>5.94bc</td>
</tr>
<tr>
<td>60,000cc</td>
<td>9.76b</td>
<td>9.76b</td>
<td>16.03bc</td>
<td>5.94bc</td>
</tr>
<tr>
<td>100,000cc</td>
<td>9.50b</td>
<td>15.29bc</td>
<td>6.51d</td>
<td>5.94bc</td>
</tr>
</tbody>
</table>

Initial value indicated mean ± SE.

Studies et al. (2013) indicated that low temperature delayed ripening of tomato (Madison and Unicorn). Changes in acidity are also important in the development of the characteristics taste in many fruits, and the organic acid decreased in most fruits during ripening (Kays and Paull, 2004).

The highest vitamin C was performed by 10,000cc film at 5°C and 11°C and 20,000cc film at 24°C, and the lowest showed by 60,000cc film at 5°C, 11°C and 24°C (Table 1). The vitamin C content of all treated tomatoes decreased during the storage period. The average value of vitamin C was 8.12, 8.46, and 9.52mg/100g fresh weight at 5°C, 11°C and 24°C, respectively. Storage for 6 days in carbon dioxide-enriched atmospheres resulted in a reduction in ascorbic acid content of sweet pepper kept at 13°C (Wang, 1977).

Atmospheric modification reduces physiological and chemical changes of fruits and vegetables during storage, and loss of ascorbic acid can be reduced by storing apples in a reduced oxygen atmosphere, and high carbon dioxide concentration in the storage atmosphere caused degradation of vitamin C in fresh-cut kiwifruit slices (Lee and Kader, 2000).

The appropriate MAP condition for both 5°C and 11°C is 20,000cc film, and for 24°C is 40,000cc film because those films increase storability, maintain visual quality, soluble solids and retain firmness. Those films would be allowing adequate gas exchanges for tomatoes. Moreover, O₂ permeability films can provide fresher tomatoes, safe public health, help avoid chemicals during storage, and also help to earn foreign currency by satisfying the buyers as well as consumers.

Acknowledgement
This study was supported by Bio-industry Technology Development Program (No. 111080-03), Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea.

Literature Cited


방울토마토의 MA 저장성 향상을 위한 비천공 breathable 필름 구명

이승람 모하메드 조희률1 · 밀리 마하무다 야터1 · 이환종1 · 이경수1 · 홍성미1 · 정민재1 · 김일섭1
홍순관2 · 최인이1,3 · 백준필3 · 강호민1,3 *
1강원대학교 원예학과, 2강원대학교 생명건강공학과, 3강원대학교 농업생명과학연구원

작 용. 본 연구는 방울토마토의 MA 저장시 저장기간 연장과 품질 유지를 위한 비천공 breathable 필름 종류를 구명하고자 진행되었다. 강원도에 위치한 플라스틱 하우스에서 수경재배한 토마토를 담적색기에 수확하여 5℃, 11℃, 그리고 24℃에서 산소투과도가 각기 다른 비천공 breathable 필름(10,000; 20,000; 40,000; 60,000; 80,000; 100,000 cc/m².day.atm)과 천공필름으로 포장하여 저장하였다. 저장 중 생체중 감소율은 세가지 온도 모두에서 비천공 breathable 필름처리구에서는 0.6% 미만이었으나, 천공필름은 5℃는 2.93%, 11℃는 13.29%, 그리고 24℃에서는 27.24%에 달하였다. 포장내 이산화탄소와 산소 농도를 봉 때 5℃와 11℃에서 20,000 cc 필름, 24℃에서 40,000 cc 필름이 MA 조건에 근접한 수치를 보였다. 에틸렌 농도는 산소투과도가 가장 높은 10,000 cc에서 모든 온도에서 가장 높았다. 저장 중 외관상 품질과 최종일 측정한 것과 달동도는 5℃와 11℃의 20,000 cc 필름, 24℃의 40,000 cc필름이 높은 수치를 나타내었다. 그러나 산소와 비타민 C 함량은 필름처리에 대한 일정한 경향을 보이지 않았다. 이상의 결과로 보았을 때, MA 저장시 포장내 대기조성과 저장 종료일의 과실 품질 등을 비교한 결과 방울토마토는 5℃와 11℃에서 20,000 cc 필름, 24℃에서는 40,000 cc 필름이 적합하였다.

추가 주제어 : 정도, 당도, 비타민 C, 외관 품질